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SATURN S-IVB-209 STAGE ACCEPTANCE FIRING REPORT

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PREPARED BY:
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SATURN S-IVB TEST PLANNING
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PREPARED FOR:
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SPACE ADMINISTRATION
UNDER NASA CONTRACT NAS7-101

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ABSTRACT

This report presents an evaluation of the Saturn S-IVB-209 stage acceptance firing that was conducted at the Sacramento Test Center on 20 June 1967. Included in this report are stage and ground support equipment deviations associated with the acceptance firing configuration.

The acceptance firing test program was conducted under National Aeronautics and Space Administration Contract NAS7-101, and established the acceptance criteria for buyoff of the stage.

DESCRIPTORS

Saturn S-IVB-209 Stage

Saturn S-IVB-209 Stage Test Evaluation

J-2 Engine

Complex Beta

Countdown Operations

Saturn S-IVB-209 Stage Acceptance Firing

Saturn S-IVB-209 Stage Test Configuration

Sacramento Test Center

Sequence of Events

PREFACE

The purpose of this report is to document the evaluation of the Saturn S-IVB-209 stage acceptance firing as performed by Douglas personnel at the Sacramento Test Center.

This report, prepared under National Aeronautics and Space Administration Contract NAS7-101, is issued in accordance with line item 129 of the MSFC *Data Requirements List 021*, dated 15 September 1966.

This report evaluates stage test objectives, instrumentation, and configuration deviations of the stage, test facility, and ground support equipment.

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INTRODUCTION

1. INTRODUCTION

1.1 General

This report was prepared at the Douglas Huntington Beach Missile & Space Systems Division by the Saturn S-IVB Test Planning and Evaluation (TP&E) Committee for the National Aeronautics and Space Administration under Contract NAS7-101.

Activities connected with the Saturn S-IVB-209 stage included a prefiring checkout and the acceptance firing. Checkout started at the subsystem level and progressed to completion with the integrated systems test and the simulated acceptance firing. The information contained in the following sections documents and evaluates all events and test results of the acceptance firing which was completed on 20 June 1967. The tests were performed at the Complex Beta, Test Stand I, Sacramento Test Center (STC).

1.2 Background

The S-IVB-209 stage was assembled at the Huntington Beach Missile & Space Systems Division. A checkout was performed in the Vertical Checkout Laboratory (VCL) prior to shipping the stage to STC. The stage was delivered to STC on 10 March 1967 and installed on Test Stand I on 15 May 1967. The stage was ready for acceptance firing on 12 June 1967.

The APS modules were shipped to the Santa Monica checkout laboratory for leak and functional checks. The modules were then shipped to Sacramento for stage interface checks. No confidence firings of these modules were scheduled.

Table 1-1 lists the milestones of the Saturn S-IVB-209 stage events and dates of completion.

1.3 Objectives

All test objectives outlined in Douglas Report No. SM-47459A, *Saturn S-IVB-209 Stage Acceptance Firing Test Plan*, dated February 1967 and revised 29 May 1967 were successfully completed.

Stage acceptance objectives which provided maximum system performance evaluation were as follows:

a. Countdown control and operational capability verification

b. J-2 engine system performance verification

c. Oxidizer system performance verification

d. Fuel system performance verification

e. Pneumatic control system performance verification

f. Propellant utilization system performance verification

g. Stage data acquisition system performance verification

h. Stage electrical control and power system performance verification

i. Hydraulic system performance and J-2 engine gimbal control performance verification

j. Structural integrity verification

k. Auxiliary propulsion system stage interface compatibility verification

l. Ambient repressurization system performance verification.

TABLE 1-1
MILESTONES, SATURN S-IVB-209 STAGE

EVENT	COMPLETION DATE
Tank Assembly	8 July 1966
Proof Test	26 July 1966
Insulation and Bonding	6 Sept 1966
Stage Checkout and Join J-2 Engine	28 Nov 1966
Systems Checkout	7 Feb 1967
Ship to STC	10 March 1967
Stage Installed on Test Stand	15 May 1967
Ready for Acceptance Firing	12 June 1967
Acceptance Firing	20 June 1967
Propellant Loading for Special Tests	23 June 1967
Abbreviated Postfire Checkout on Stand	6 July 1967
Ready for Storage	11 July 1967

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SUMMARY

2. SUMMARY

The S-IVB-209 stage was acceptance fired on 20 June 1967 at Complex Beta, Test Stand I, Sacramento Test Center. The countdown was designated as CD 614085. The mainstage firing duration was 455.95 sec; engine cutoff was initiated through the PU processor when LOX was depleted below the 1 percent level.

2.1 Countdown Operations

2.1.1 CD 614084

CD 614084 (run 1A) was initiated on 13 June and proceeded smoothly with only one anomaly; LH2 depletion sensor No. 1 cycled dry for 28 ms during LH2 loading at the 30 percent level.

At 822.9 sec prior to simulated liftoff the "Engine Ready" scan received an ignition detection signal that was attributed to a temperature differential across the probe resulting from the thrust chamber childown. This halted the automatic program and the stage was secured automatically. A manual thrust chamber chilldown sequence was then conducted with no recurrence of the problem.

Run 1B was initiated and during the start sequence, a switch selector complement error was received halting the automatic program and the stage was secured manually. At this point, the countdown was scrubbed.

2.1.2 CD 614085

CD 614085 (run 2A) was initiated on 19 June 1967 and proceeded smoothly to a successful acceptance firing on 20 June 1967. The following anomalies were experienced during the countdown:

a. Shortly after engine start, an abnormal decrease was noted in the LOX tank ullage pressure as a result of a temporary anomaly in the LOX tank pressurization module.

b. ESC occurred 685 ms later than expected due to a slow opening of the LOX prevalve. This was attributed to the use of the new Sterer actuation control modules. The valve also exhibited an erratic talkback on the hardwire "CLOSED" indication during the postfiring special test. The prevalve was replaced.

2.2 J-2 Engine System

The J-2 engine (S/N 2083) exhibited operational characteristics compatible with stage design requirements and consistent with prior test data and with the Engine Model Specification R-2158b.

2.3 Oxidizer System

Due to a malfunction of the LOX tank pressurization control module, LOX NPSH fell below the minimum acceptable level for a 20-sec period shortly after Engine Start Command; however, there were no detrimental effects to the J-2 engine or to the remainder of the acceptance firing. With the exception of the above anomaly, the oxidizer system performance was acceptable.

2.4 Fuel System

The fuel system performed as designed and supplied LH2 to the engine LH2 pump inlet within the limits required for satisfactory engine performance.

2.5 Pneumatic Control and Purge System

The pneumatic control and purge system performed satisfactorily throughout the acceptance firing. The helium supply to the system was adequate for both pneumatic valve control and purging; the regulated pressure was maintained within acceptable limits and all components functioned normally.

2.6 Propellant Utilization (PU) System

The PU system performed satisfactorily and accomplished all the design objectives.

2.7 Data Acquisition System

The data acquisition system performed satisfactorily throughout the acceptance firing. One hundred and seventy five measurements were active of which 2 failed resulting in a measurement efficiency of 98.86 percent.

2.8 Electrical Power and Control Systems

The electrical power and control systems performed satisfactorily throughout the acceptance firing. All firing objectives were satisfied and all system variables operated within design limits.

2.9 Hydraulic System

The hydraulic system operated properly supplying pressurized fluid to the servo-actuators. All specified test objectives were achieved and all system variables operated within design limits.

2.10 Flight Control System

The dynamic response of the hydraulic servo-thrust vector control system was measured while the J-2 engine was gimbaled during the acceptance firing. The performance of the pitch and yaw hydraulic servo control systems was satisfactory.

2.11 Structural Systems

Structural integrity of the stage was maintained for the vibration, temperature, and thrust load conditions of the acceptance firing. A postfiring visual inspection of the stage revealed no debonding or other structural defects resulting from cryogenic loading and firing.

2.12 Thermoconditioning and Purge System

The thermoconditioning and purge system functioned properly during the acceptance firing. All system temperatures and flowrates were maintained within design limits.

2.13 Reliability and Human Engineering

All malfunctions of Flight Critical Items were investigated and documented. A Human Engineering evaluation has been conducted in support of the acceptance firing.

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TEST CONFIGURATION

3. TEST CONFIGURATION

This section describes the stage and ground support equipment (GSE) deviations and modifications from the flight configuration affecting the acceptance firing. Additional details of specific system modifications are discussed in appropriate sections of this report. Details of the S-IVB-209 stage configurations are presented in Douglas Report No. 1B66532, *S-IVB/IB Stage End-Item Test Plan.*

Figure 3-1 is a schematic of the S-IVB-209 stage propulsion system and shows the telemetry instrumentation transducer locations from which the test data were obtained. The functional components are listed in table 3-1. Hardwire measurements are noted in the appropriate subsystem schematics included in this report. The propulsion system orifice characteristics and pressure switch settings are presented in tables 3-2 and 3-3. J-2 engine S/N 2083 was installed.

The propulsion GSE (figure 3-2) consisted of pneumatic consoles "A" and "B," two propellant fill and replenishing control sleds, a vacuum system console, and a gas heat exchanger.

3.1 Configuration Deviations

Configuration deviations required for the acceptance firing are discussed in Douglas Report No. SM-47459A, *Saturn S-IVB-209 Stage Acceptance Firing Test Plan.* Significant configuration changes to the stage and GSE during the acceptance firing are discussed in the following paragraphs.

3.1.1 Propulsion System

a. Stage propellant vent and bleed systems were connected to the facility vent system.

b. The stage portions of the propellant and pneumatic quick-disconnects were replaced with hardlines.

c. A converging water-cooled diffuser was installed in the engine thrust chamber exit to reduce the possibility of sideloads induced by jet stream separation.

d. A reusable J-2 engine ignition detection probe was installed in place of the S-IB expendable probe.

3.1.2 Propellant Utilization System

a. The propellant loading fast-fill sensors installed on the instrumentation probes were used in the indicating mode only.

3.1.3 Electrical Power System

a. Model DSV-4B-170 battery simulators were used to supply stage internal power.

b. Model DSV-4B-727 primary battery simulators were used in place of primary flight batteries.

3.1.4 Electrical Control System

a. The instrument unit and S-IVB/IB stage electrical interfaces were simulated by GSE.

b. Two Model DSV-4B-188B APS simulators were used to provide APS module electrical loads to the stage control signals.

c. The electrical umbilicals remained connected throughout the acceptance firing.

3.1.5 Data Acquisition System

a. The MSFC Basic Static Firing Measurement Program hardwire transducers were installed.

b. All instrumentation parameters without transducers, and those disconnected for hardwire usage, were left as open channels.

c. Measurement D0576 (LH2 Tank Ullage Press) - Strain gage flight transducer P/N 1B40242-509 was RF sensitive and was replaced by pot transducer P/N 1A72913-539.

3.1.6 Forward Environmental Control System

a. Fluid for the forward thermoconditioning system was supplied by Model DSV-4B-359 Servicer.

3.1.7 Secure Range Safety Command System

a. The engine cutoff command output from Range Safety Systems 1 and 2 was disconnected and stowed.

b. Pulse sensors were attached to the output of the exploding bridgewire (EBW) firing units.

3.1.8 Structural Systems

a. The main and auxiliary tunnel covers were not installed.

b. The stage was mounted on the Model DSV-4B-540 Dummy Interstage.

3.1.9 GSE and Facilities

a. Resistance wire fire detection system was installed for monitoring critical areas of the stage, GSE, and facilities.

b. GH2 leak detection system was installed for monitoring critical areas of the stage, GSE, and facilities.

c. Blast detectors were installed in the test area for monitoring ranges of 0 to 25 psi overpressure.

d. Model 742 static firing hazardous gas shield, thrust cone water spray Firex, cryogenic spill pan, forward skirt support ring and vent port covers were installed.

e. Model 601 flame resistant protective firing cover was installed to enclose the forward skirt area.

f. An auxiliary propellant tank pressurization system was installed using a GSE ambient helium source.

g. Model DSV-4B-618 Engine Unlatch Restrainer Links were installed to restrain the J-2 engine during start transient sideloads.

h. Two O_2 content analyzers were installed in the thrust structure.

TABLE 3-1 (Sheet 1 of 4)
S-IVB-209 STAGE HARDWARE LIST

ITEM NO.*	PART NO.	NAME
1	7851861-1	Disconnect, LH2 tank pressurization
2	1B65673-1	Valve, check, LH2 tank prepressurization line
3	7851823-503	Disconnect, ambient helium fill
4	1B53817-505	Valve, hand, 3-way, LOX vent and relief valve purge line
5	1B53817-505	Valve, hand, 3-way, LH2 and LOX fill and drain valves, nonpropulsive vent and LH2 chilldown valve purge line
6	1B51361-1	Valve, check, LH2 fill and drain valve and nonpropulsive vent purge line
7	1B63206-1	Orifice, ambient helium fill, 65 scfm
8	1B51361-1	Valve, check, control helium fill
9	1A57350-507	Module, control helium fill
10	1A49963-1	Sphere, control helium, 4.5 std cu ft
11	1B68260-1	Disconnect, LH2 tank vent
12	1B66932-501	Disconnect, LH2 fill and drain
13	1B40622-505	Orifice, LH2 fill and drain valve purge line, 15 scfm
14	1B66692-501	Module, actuation control, LH2 fill and drain valve
14 A&B	1B67481-1	Valve, check, LH2 fill and drain valve actuation control module vent
15	1B41065-1	Disconnect, common bulkhead vacuum system
16	1A48240-505	Valve, LH2 fill and drain
17	1B66932-501	Disconnect, LOX fill and drain
18	1B51361-1	Valve, check, LOX fill and drain valve purge line
19	1B40622-505	Orifice, LOX fill and drain valve purge line, 15 scim
20	1A48240-505	Valve, LOX fill and drain
21	1B66692-501	Module, actuation control, LOX fill and drain valve
21 A&B	1B67481-1	Valve, check, LOX fill and drain valve actuation control module vent
22	7851844-501	Disconnect, cold helium fill and LOX tank prepressurization
23	1B57781-505	Module, cold helium dump
24	1B40824-507	Valve, check, cold helium fill line
25	1B42290-505	Module, LOX tank pressure control
26	1B40824-503	Valve, check, cold helium fill and LOX prepressurization line
27	1A49991-1	Plenum, LOX tank pressurization, 250 std cu in.
28	7851830-517	Switch, pressure, LOX tank pressurization regulator backup, P/U 465 +20, -15 psia, D/O 350 +20, -15 psia

* Indicates location in figures 3-1 and 3-2.   P/U = Pickup   D/O = Dropout

TABLE 3-1 (Sheet 2 of 4)
S-IVB-209 STAGE HARDWARE LIST

ITEM NO.*	PART NO.	NAME
29	1B63046-513	Orifice, LOX tank pressurization, heat exchanger primary, 0.03218 $in.^2$ effective area
30	1B63047-513	Orifice, LOX tank pressurization, heat exchanger bypass, 0.02291 $in.^2$ effective area
31	DELETED	
32	1A49958-517	Disconnect, mainstage OK pressure switch checkout
33	1A49958-519	Disconnect, thrust chamber jacket purge and childown
34	1B43657-509	Module, pneumatic power control
35	1A48857-501	Plenum, control helium, 100 std cu in.
36	1B55200-505	Module, LH2 tank pressure control
	1B64443-505	Orifice, undercontrol mode, 0.0444 $in.^2$ effective area
	1B64443-505	Orifice, overcontrol mode, 0.0777 $in.^2$ effective area
	1B64443-505	Orifice, step flow, 0.1392 $in.^2$ effective area
37	1B51361-1	Valve, check, LH2 nonpropulsive vent purge line
38	1B40622-501	Orifice, LH2 nonpropulsive vent purge line, 1 scfm
39	1B59265-1	Orifice, nonpropulsive vent, 2.180 in. dia
40	1B59265-1	Orifice, nonpropulsive vent, 2.180 in. dia
41	7851860-537	Switch, pressure, LH2 prepressurization and ground fill, P/U 34 psia, D/O 31 psia min
42	7851860-541	Switch, pressure, LH2 flight control, P/U 29.5 psia, D/O 26.5 psia
43	1A67005-507	Switch, pressure, LH2 tank orbital vent initiation, P/U 35.25 $\pm$0.75 psia, D/O 31 psia min
44	1B53817-505	Valve, 3-way, LH2 tank pressure switch shutoff
45	1A49988-1	Valve, directional control, LH2 vent
46	1A49591-531	Valve, relief, LH2 tank, crack 40 psia max, reseat 37 psia min
47	1A48257-509	Valve, vent and relief, LH2 tank, crack 39 psia max, reseat 36 psia min
48	1A48858-1	Sphere, storage, cold helium (6 each)
49	1B58100-1	Probe, LH2 temperature sensor
50	1A48431-509	Probe, LH2 mass sensor
51	1A79603-509	Probe, LOX temperature sensor
52	1A48430-509	Probe, LOX mass sensor
53	1A49421-501	Pump, LH2 chilldown

* Indicates location in figures 3-1 and 3-2. P/U = Pickup D/O = Dropout

TABLE 3-1 (Sheet 3 of 4)
S-IVB-209 STAGE HARDWARE LIST

ITEM NO.*	PART NO.	NAME
54	1A58854-1	Orifice, LOX chilldown pump purge line, 600 sccm at 475 psid
55	1A58347-505	Module, LOX chilldown pump purge
55A	1B40622-511	Orifice, LOX chilldown pump purge module bypass, 10 scim at 475 psid
56	1A49423-507	Pump, LOX chilldown
57	1A49964-501	Valve, check, LOX chilldown return line
58	7851847-535	Switch, pressure, LOX chilldown pump purge regulator backup, P/U 53 psia max, D/O 49 psia min
59	114-109 (PESCO)	Valve, relief, LOX chilldown pump motor container, crack and reseat 65 to 85 psia
60	1A67913-1	Valve, vent, LOX chilldown pump motor container
61	1A49965-521	Valve, shutoff, LOX chilldown line
62	1A89104-509	Flowmeter, LOX chilldown line
63	1A87749-1	Strainer, LOX chilldown pump discharge
64	1A49968-509	Prevalve, LOX
65	1B66692-501	Module, actuation control, directional valve, LH2 vent
65 A&B	1B67481-1	Valve, check, directional valve actuation control module vent
66	1B66692-501	Module, actuation control, LH2 vent and relief valve
66 A&B	1B67481-1	Valve, check, LH2 tank vent and relief valve actuation control module vent
67	1A49964-501	Valve, check, LH2 chilldown return line
68	1B53817-505	Valve, 3-way, LOX tank pressure switch shutoff
69	7851847-533	Switch, LOX prepressurization, flight, and ground fill control, P/U 40 psia max, D/O 37 psia min
70	1B40622-501	Orifice, LOX tank pressure sensing line purge
71	1A49968-507	Prevalve, LH2
72	1B66692-501	Module, actuation control, prevalves and chilldown valves
72 A&B	1B67481-1	Valve, check, LOX vent and relief valve actuation control module vent
73	1B40622-507†	Orifice, LH2 chilldown shutoff valve purge line, 14 scfm
74	1A49965-523	Valve, shutoff, LH2 chilldown pump discharge
75	1A89104-509	Flowmeter, LH2 chilldown pump discharge

* Indicates location in figures 3-1 and 3-2. P/U = Pickup D/O = Dropout

† Flight orifice--for acceptance firing, purge function is supplied by facility orifice 65 scfm at 1,600 psia

TABLE 3-1 (Sheet 4 of 4)
S-IVB-209 STAGE HARDWARE LIST

ITEM NO.*	PART NO.	NAME
76	1B53920-503	Valve, check, LH2 chilldown pump discharge
77	1B52985-501	Strainer, LH2 chilldown pump discharge
78	1B51361-1	Valve, check, LOX vent and relief valve purge line
79	1B63206-1	Orifice, flow, LOX vent and relief valve purge line, 65 scfm
80	1A49590-517	Valve, relief, LOX tank, crack 45 psia, reseat 42 psia
81	1A48312-505	Valve, vent and relief, LOX tank, crack 44 psia, reseat 41 psia
82	1B66692-501	Module, actuation control, LOX vent and relief valve
83	1B56804-1	Module, engine purge control
84	1A67002-509	Switch, pressure, engine purge regulator backup, P/U 130 psia min, D/O 105 psia min
85	1A49958-521	Disconnect, engine start sphere vent and relief valve drain
86	1A49958-515	Disconnect, engine control helium sphere fill
87	1A49958-523	Disconnect, engine start sphere fill

* Indicates location in figures 3-1 and 3-2. P/U = Pickup D/O = Dropout

TABLE 3-2 (Sheet 1 of 3)
S-IVB-209 STAGE AND GSE ACCEPTANCE FIRING ORIFICES

ITEM*	DESCRIPTION	ORIFICE SIZE OR NOMINAL FLOWRATE	COEFFICIENT OF DISCHARGE	EFFECTIVE AREA (in.^{2})
	STAGE			
7	Ambient helium fill	65 scfm	--	Sintered
13	LH2 fill and drain valve purge line	15 scim at 3,200 psid	--	Sintered
19	LOX fill and drain valve purge line	15 scim at 3,200 psig	--	Sintered
29	LOX tank pressurization system heat exchanger outlet	0.219 in. dia	0.85	0.03218
30	LOX tank pressurization system heat exchanger bypass	0.185 in. dia	0.85	0.02291
36	LH2 tank pressurization module			
	Undercontrol**	0.257 in. dia		0.0444
	Overcontrol**	0.223 in. dia		0.0777
	Step**	0.323 in. dia		0.1392
38	LH2 tank nonpropulsive vent purge line	1 scfm at 3,200 psid	--	Sintered
29-40	LH2 tank nonpropulsive vent (2)	2.180 in. dia	--	3.1726
54	LOX chilldown pump purge line	600 scim at 475 psid	--	Sintered
55	LOX chilldown pump purge module	0.00166 lb/sec at 475 psig IN and 85 psig OUT	†	
55A	LOX chilldown pump purge module bypass	10 scim at 475 psid	--	Sintered

* Indicates location in figures 3-1 and 3-2.

** Discharge coefficient and effective area are calculated for overcontrol and step orifices in successive combination with the undercontrol orifice.

† Flight orifice--for acceptance firing, purge function is supplied by facility orifice of 65 scfm at 1,600 psi.

TABLE 3-2 (Sheet 2 of 3)
S-IVB-209 STAGE AND GSE ACCEPTANCE FIRING ORIFICES

ITEM*	DESCRIPTION	ORIFICE SIZE OR NOMINAL FLOWRATE	COEFFICIENT OF DISCHARGE	EFFECTIVE AREA (in.^{2})
70	LOX tank pressure sensing line purge	1 scfm at 3,200 psig	--	Sintered
73	LH2 childown valve purge line†	14 scfm at 3,000 psid	--	Sintered
79	LOX tank vent and relief valve purge line	65 scfm at 3,100 psid	†	0.00043
83	Engine pump purge module	0.00166 lb/sec at 475 psig IN and 85 psig OUT	--	0.00023
	CONSOLE A			
--	All console A stage bleeds	Variable	--	--
A9515	Pressure actuated valve and mainstage pressure switch supply	1.2 scfm	--	Sintered
A9526	J-box inerting supply	0.013 in. dia	--	--
A9533	LH2 system checkout supply	1.2 scfm	--	Sintered
A9534	LOX system checkout supply	2.0 scfm	--	Sintered
A9535	LH2 tank and umbilical purge	0.260 in. dia	0.88	0.0467
A9536	Pressure switch checkout--low pressure	1.2 scfm	--	Sintered
A9537	Pressure switch checkout--high pressure	0.044 in. dia	--	--
A9538	LH2 tank repressurization supply (ambient helium supply)	Union	--	--
A9539	Console A GN2 inerting supply	0.013 in. dia	--	--

* Indicates location in figures 3-1 and 3-2.

† Flight orifice--for acceptance firing, purge function is supplied by facility orifice of 65 scfm at 1,600 psi.

TABLE 3-2 (Sheet 3 of 3)
S-IVB-209 STAGE AND GSE ACCEPTANCE FIRING ORIFICES

ITEM*	DESCRIPTION	ORIFICE SIZE OR NOMINAL FLOWRATE	COEFFICIENT OF DISCHARGE	EFFECTIVE AREA (in.^{2})
	CONSOLE B			
--	All console B stage bleeds	Variable	--	--
--	Turbine start sphere supply	--	--	--
--	LOX tank prepressurization supply	0.096 in. dia	0.94	0.00680
A9525	Engine control sphere supply	0.125 in. dia	0.84	0.01031
A9527	LH2 tank prepressurization	0.161 in. dia	0.94	0.0094
A9528	Thrust chamber jacket purge and chilldown system	0.072 in. dia	0.89	0.00362
A9529	LOX tank and umbilical purge system	0.305 in. dia	--	--
A9540	J-box inerting supply	0.013 in. dia	--	--
A9550	Engine control sphere supply vent	--	--	--
A9552	Turbine start sphere GH2 supply vent	0.081 in. dia	0.83	0.00479
OR395	LH2 tank auxiliary pressurization	0.395 in. dia	--	--
OR396	LOX tank auxiliary pressurization	0.395 in. dia	--	--

* Indicates location in figures 3-1 and 3-2.

TABLE 3-3
S-IVB-209 STAGE PRESSURE SWITCHES

PARAMETER	PART NO.	SPECIFIED (psia)		PRETEST (psia)	
		PICKUP	DROPOUT	PICKUP	DROPOUT
LH2 Tank Pressurization System					
Flight control	7851860-541	30.0 max	26.5 min	29.26	27.17
Prepressurization and ground fill valve control	7851860-537	34.5 max	30.8 min	33.49	31.03
Orbital vent	7851860-543	35.0 ±1	30.5 min	35.24	31.92
LOX Tank Pressurization System					
LOX prepress, flight control, and ground fill valve control	7851847-533	41.0 max	36.5 min	40.02	37.57
LOX tank regulator backup	7851830-517	467.5 ±23.5	352.5 ±23.5	458.3	355.4
Pneumatic Control System					
Power control module	7851830-521	600 ±21	490 ±31	599.1	499.2
LOX chilldown pump motor container	7851847-535	54 max	49 min		
Engine pump purge	1A67002-509	130 max	105 min	125.0	114.2
J-2 Engine					
Mainstage OK No. 1	NA5-27453	515 ±30	P/U minus 62.5 ±31.5	526.70	458.30
Mainstage OK No. 2	NA5-27453	515 ±30	P/U minus 62.5 ±31.5	529.41	465.50

NOTES: All pressures listed are the average of three actuations.

P/U = Pickup

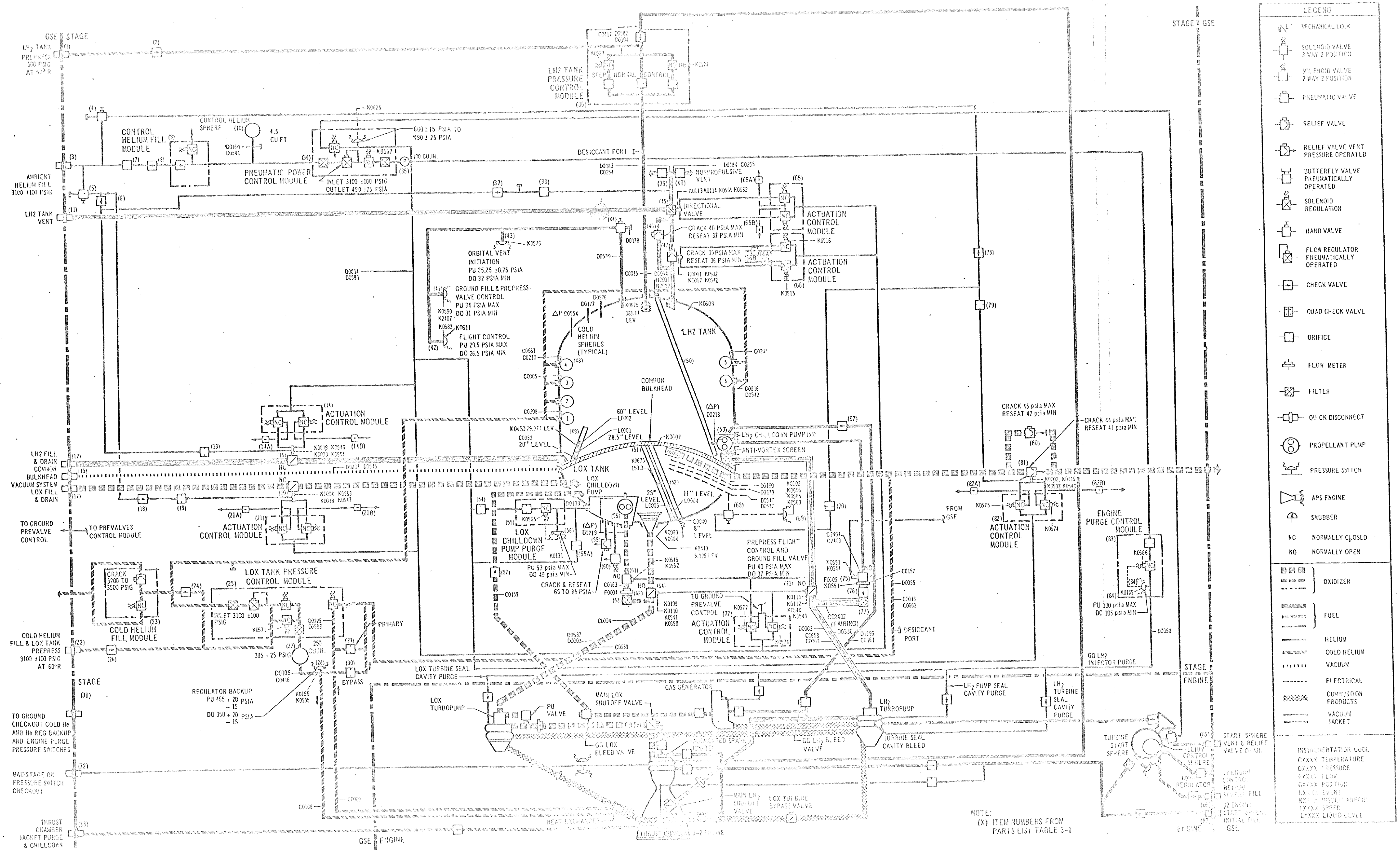

Figure 3-1. Propulsion System Configuration and Instrumentation

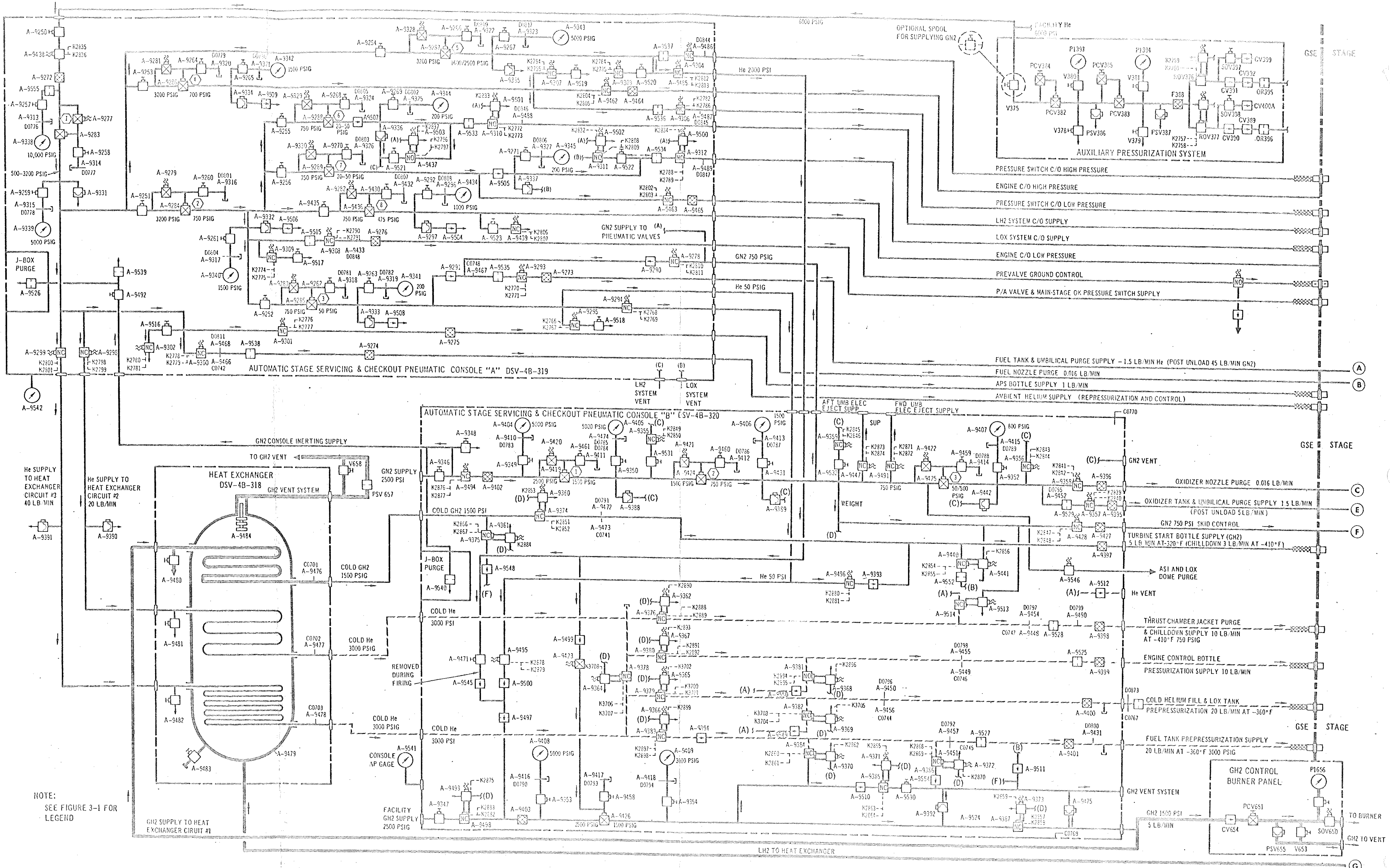

Figure 3-2. Facility Propellant and Pneumatic Loading Systems (Sheet 1 of 2)

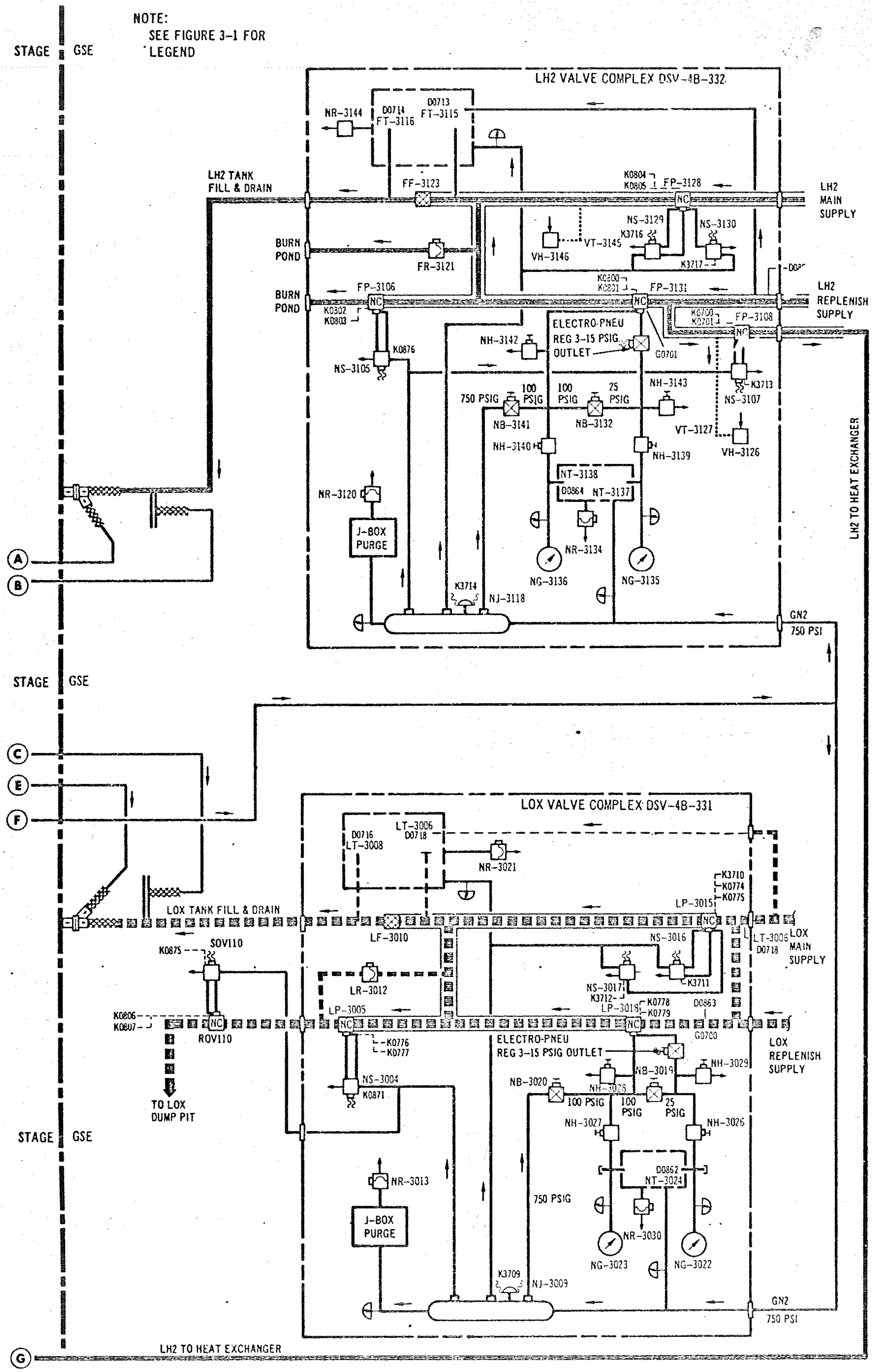

Figure 3-2. Facility Propellant and Pneumatic Loading Systems (Sheet 2 of 2)

4

COUNTDOWN OPERATIONS

4. COUNTDOWN OPERATIONS

The S-IVB-209 stage acceptance firing was successfully accomplished during CD 614085 on 20 June 1967. All phases of the acceptance firing countdown are reviewed and evaluated in the following paragraphs, which include discussions of the prefiring checkout, propellant loading, and ground support and facility operations.

4.1 Countdown 614084 (Run 1A, Run 1B)

Countdown 614084 was initiated on 13 June and proceeded smoothly through propellant loading. Two firing attempts were made on 14 June. Run 1A proceeded to T_0 -822.9 sec when an erratic augmented spark igniter (ASI) ignition detection signal was received on the "Engine Ready" scan. The automatic count was halted and the stage was recycled automatically to T_0 -25 min. The problem was isolated to an overly sensitive ignition detection probe, and the system amplifier was adjusted slightly. The acceptance firing was also modified to avoid looking for ignition detection until after the probe had been chilled down.

Run 1B was picked up at the initiation of terminal count, T_0 -25 min, at 1550 PDT and proceeded smoothly to the engine start sequence. When the computer sent the Switch Selector LOX Chilldown Pump Reset Command, it did not receive the proper complementary answer which would permit the command to be executed, and the test was manually cut off and the countdown terminated.

4.2 Countdown 614085 (Run 2A)

Countdown 614085 was initiated on 19 June. Propellant loading proceeded smoothly, although LH2 depletion sensor No. 1 cycled three times. Terminal count was initiated at 1114 hr on 20 June, and the acceptance firing successfully completed. Cutoff was automatically initiated by the PU processor due to LOX depletion (1 percent residual) after 455.95 sec of mainstage operation. All systems operated properly with the exception of the LOX tank pressurization system, which is discussed in section 7. Specific countdown times are presented in table 4-1.

4.3 Countdown 614086 (Special Tests)

After the acceptance firing, the stage was reloaded with propellants on 23 June to conduct additional tests on the LH2 chilldown system and the LH2 depletion sensors. The purpose of these tests was to investigate the effect of the LH2 chilldown duct fairing purge media upon the LH2 pump chilldown. The data obtained from these tests should provide some insight into the abnormal chilldowns that occurred during the S-IVB-207 and 208 acceptance firings. These data are presently being analyzed.

4.4 Checkout

The modifications, procedures, and checkouts performed for the acceptance firing were initiated on 10 March 1967, when the stage was received at the Sacramento Test Center, and continued through 12 June when the stage was ready for the acceptance firing. The handling and checkout procedures that were used for the prefiring and post-firing checkouts are described in Douglas Report DAC 56501, *Narrative End Item Report on Saturn S-IVB-209, Volume 1, SSC,* dated March 1967.

After the prefire modifications and limited prefire checkout were performed at the Vertical Checkout Laboratory, the stage was installed on Complex Beta Test Stand I on 15 May. The prefire checkout of the stage was completed 4 weeks later; the "Ready for Acceptance Firing" milestone was met on 12 June 1967.

4.5 Cryogenic Loading

The S-IVB-209 stage was successfully loaded with LOX, LH2, and cold helium.

4.5.1 LOX Loading

The LOX loading procedures were conducted as specified in Task 41 of the Countdown Manual. Preparations were completed and computer controlled loading operations were initiated without incident. Loading data for CD 614085 are presented in figure 4-1.

4.5.2 LH2 Loading

The LH2 loadings were conducted as specified in Task 42 of the Countdown Manual and proceeded smoothly, although LH2 depletion sensor No. 1 cycled several times during CD 614085, run 2A. LH2 loading data for CD 614085 are presented in figure 4-2.

4.5.3 Cold Helium Loading

Cold helium was loaded after the completion of LH2 loading. Satisfactory temperatures and pressures were attained although, due to a short chill-down period, the temperature was slightly higher than normal. Data from CD 614085 are presented in figure 4-3.

4.6 GSE Performance

4.6.1 GH2 Supply System

The GH2 supply system performed adequately. Start sphere chilldown and loading were satisfactorily accomplished. At Engine Start Command, the engine start sphere conditions were within the required limits. Data are presented in figure 4-4.

4.6.2 Helium Supply System

The helium supply system functioned adequately. Propellant tank prepressurization, thrust chamber chilldown, cold helium spheres loading, and stage and engine control sphere loading were all satisfactorily accomplished. Following each prepressurization cycle the ambient helium supply pressure (D0778) shifted upward, due to a regulator shift. This has occurred on other firings and is not considered abnormal. Data are presented in figures 4-5 through 4-7.

4.7 Countdown Problem Summary

4.7.1 Countdown 614084

This countdown was aborted when no ignition was obtained at T_0 +150 sec, and manual cutoff was initiated when it was evident that a malfunction had occurred. The following problems were encountered:

a. While the bonnet screws on the LOX main fill valve were being torqued during Task 7, Propellant Transfer Lines Preparation and Controls Check, the valve cycled closed. Investigation of the closing of the valve revealed that it was closed from an interlock command sent during Task 9, Redline Checks.

b. During the terminal count, at T_0 -822.9 sec, the engine control bus power was lost and no power was on the engine bus. Investigation revealed that when the computer scanned the engine for a readiness check, it found power on the engine ignition detection circuit. The computer automatically turned off the engine control bus power and returned the count to T_0 -25 min, as programmed. A manual check of the situation could not duplicate the problem, so the countdown was restarted as run 1B.

c. During the terminal count of run 1B at T_0 +150 sec, or at the time of engine ignition, no ignition occurred and manual cutoff was initiated. Investigation revealed that when the computer program gave the command for LOX chilldown pump reset, it did not receive the complementary answer that would permit execution of the command. The test was manually cut off and the countdown was terminated.

   After considerable troubleshooting, three relays within the computer control equipment were replaced. Although the precise cause of the probelm was not pinpointed, it is felt that the probable cause was a single, random malfunction in the response conditioner.

4.7.2 Countdown 614085

Five problems were encountered during this countdown; however, none of the problems required a delay in countdown time.

a. During Task 14, Abort Mode Checks, the forward bus No. 1 power supply malfunctioned because a defective fan system caused it to overheat. The unit was replaced.

b. During Task 39, LOX loading, the digital events recorder malfunctioned and required reloading.

c. The LH2 depletion sensor No. 1 cycled twice from wet to dry at the 31, 34, and 60 percent levels for durations of 7, 12, and 9 ms, respectively, then indicated normally.

d. The main LH2 storage tank shutoff valve, ROV-408, was reported to be leaking externally during the firing.

e. At approximately T_0 -1 hr, the safety cutoff-gas generator exhaust temperature measurement began to indicate erratically.

4.8 Atmospheric Conditions

The atmospheric conditions at specific times during the countdowns are presented in the following paragraphs.

4.8.1 Countdown 614084

Time (PDT	1000	1200	1400	1600
Wind speed (knots)	3	4	9	6
Wind direction (deg)	200	290	280	270
Barometric pressure (in. Hg)	29.85	29.84	29.82	29.78
Ambient temperature (deg F)	75	79	85	88
Dew point (deg F)	54	55	53	47

4.8.2 Countdown 614085

Time (PDT)	0800	0900	1000	1100	1200
Wind speed (knots)	3	4	4	3	4
Wind direction (deg)	170	200	200	260	210
Barometric pressure (in. Hg)	29.91	29.89	29.88	29.86	29.86
Ambient temperature (deg F)	61	65	70	75	79
Dew point (deg F)	33	54	56	57	56

TABLE 4-1
TERMINAL COUNTDOWN SEQUENCE (CD 614085)

EVENT	TIME FROM T_0 (sec)
Start sphere purge supply OPEN	-1230.144
Thrust chamber purge CLOSED	-1200.097
Thrust chamber chilldown OPEN	-1199.966
Start sphere purge supply CLOSED	-873.332
Start sphere GH2 fill supply OPEN	-869.383
LOX chilldown pump ON	-598.228
LH2 chilldown pump ON	-595.057
LH2 prevalve CLOSED	-591.385
LOX prevalve CLOSED	-591.195
Start sphere GH2 fill CLOSED	-327.595
Start sphere supply vent OPEN	-327.458
LOX tank vent valve CLOSED	-160.672
LH2 tank vent valve CLOSED	-163.319
Cold helium regulator backup switch ENABLED	-92.493
LOX fill and drain valve CLOSED	-52.149
LH2 fill and drain valve CLOSED	-51.087
LH2 directional vent to flight position	-31.951
Cold helium sphere supply OFF	-3.444
Engine control sphere fill CLOSED	-3.360
Simulated Liftoff (11:39:34.000)	0
Engine pump purge OFF	90.824
LH2 prevalve OPEN	150.155
LOX prevalve OPEN	150.570
LH2 chilldown pump OFF	151.574
LOX chilldown pump OFF	151.663
Engine Start Command	151.847
LOX pressurization system ON	152.709
Step pressurization	452.057
Engine Cutoff Command	610.682

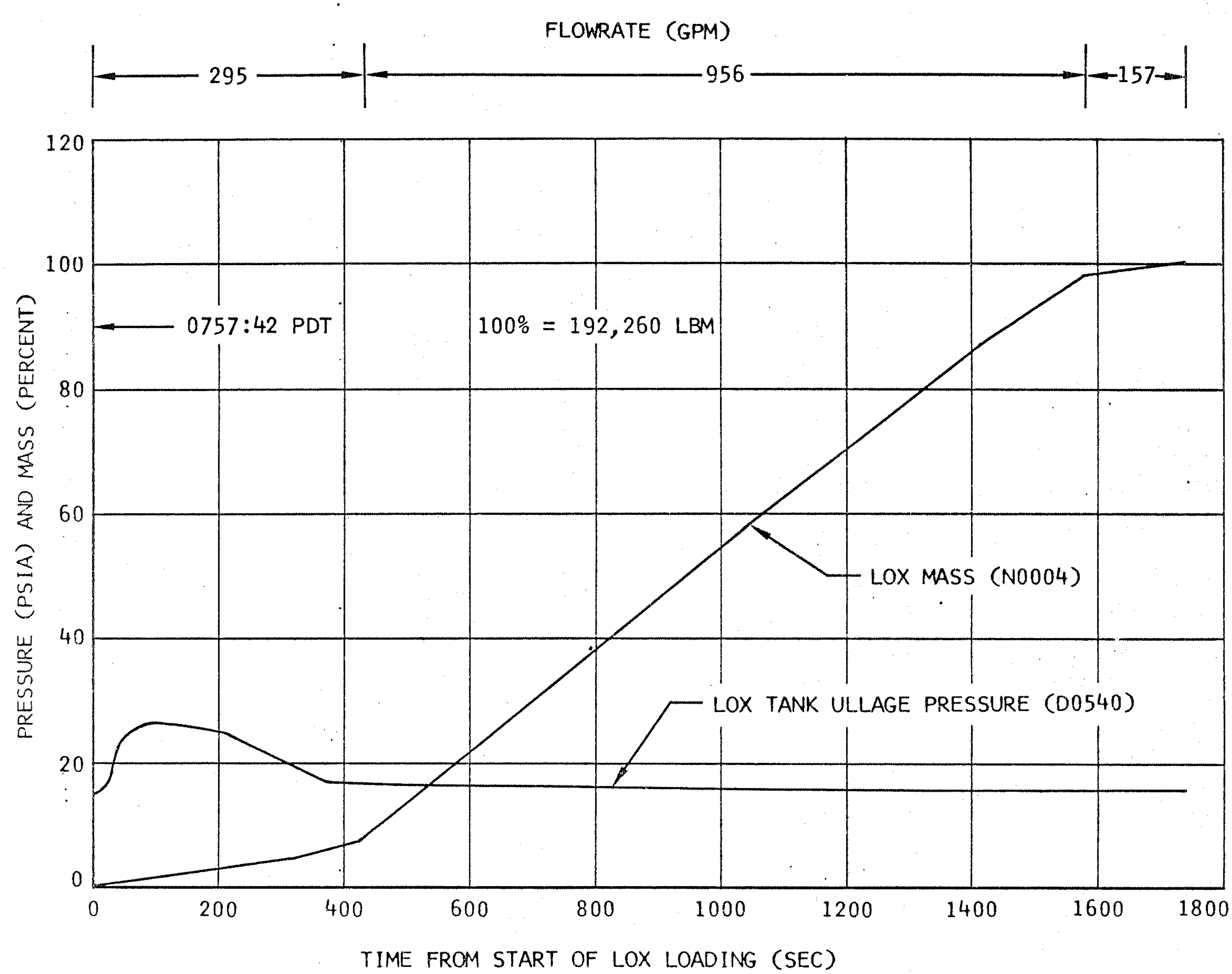

Figure 4-1. LOX Tank Loading

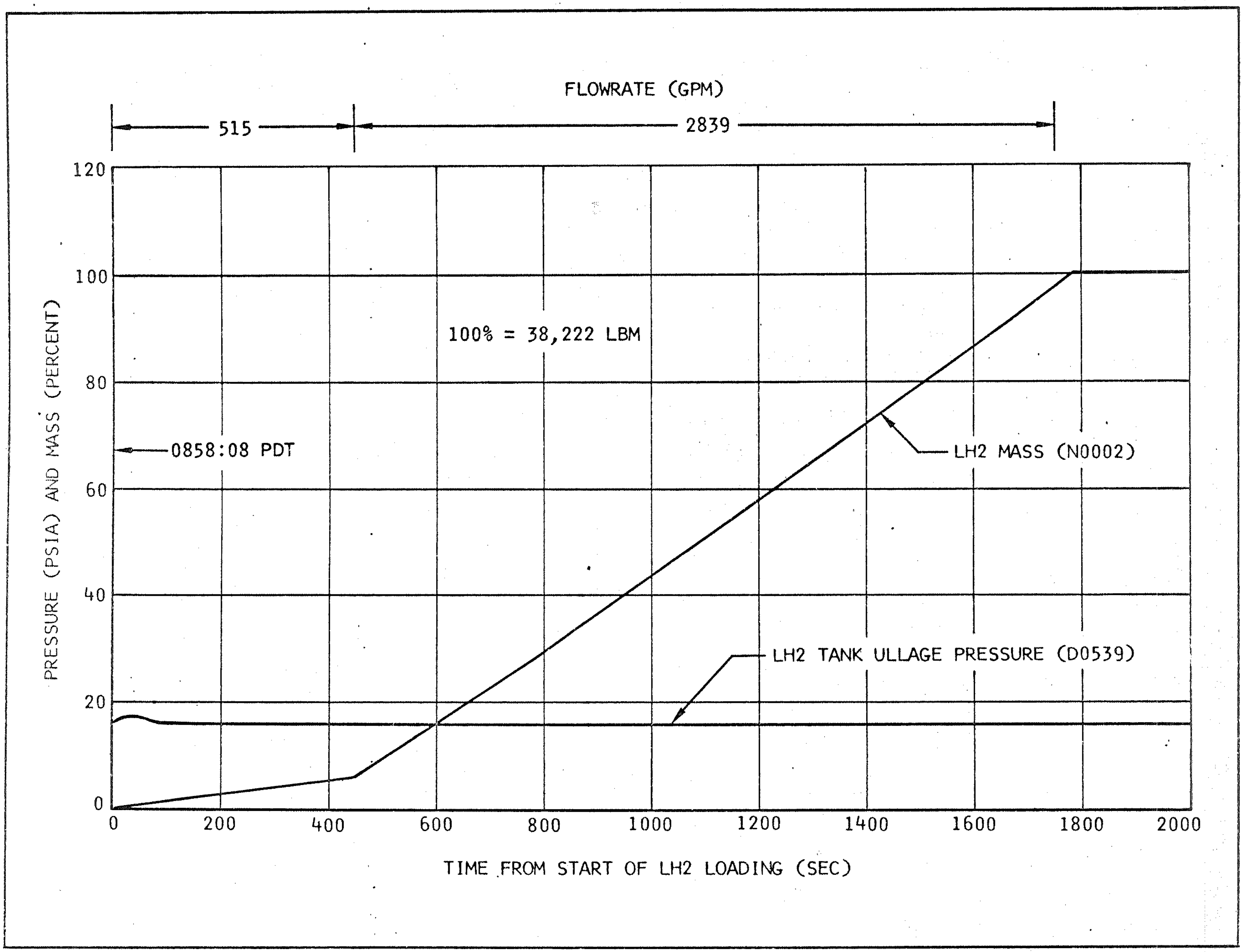

Figure 4-2. LH2 Tank Loading

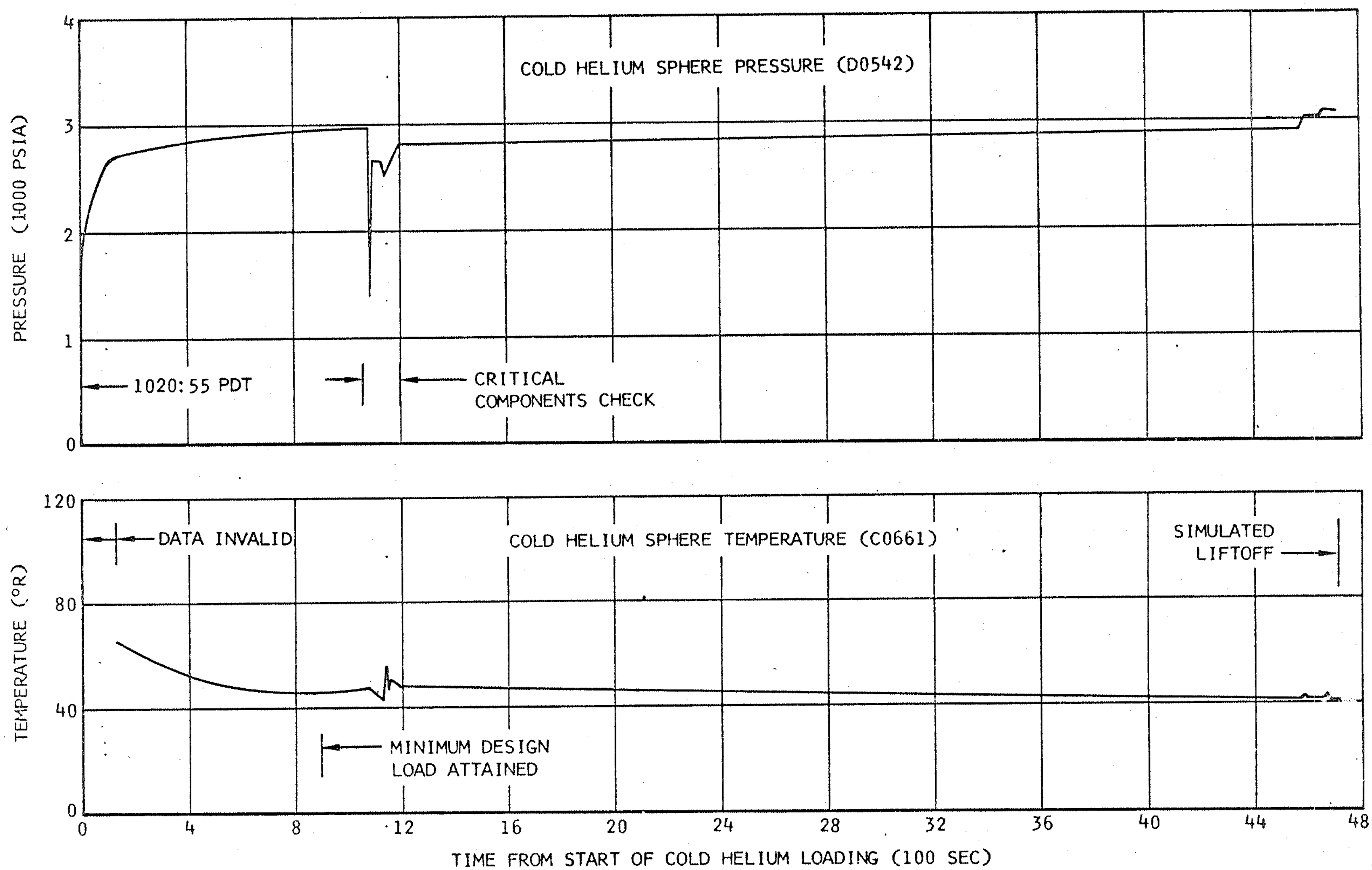

Figure 4-3. Cold Helium System Loading

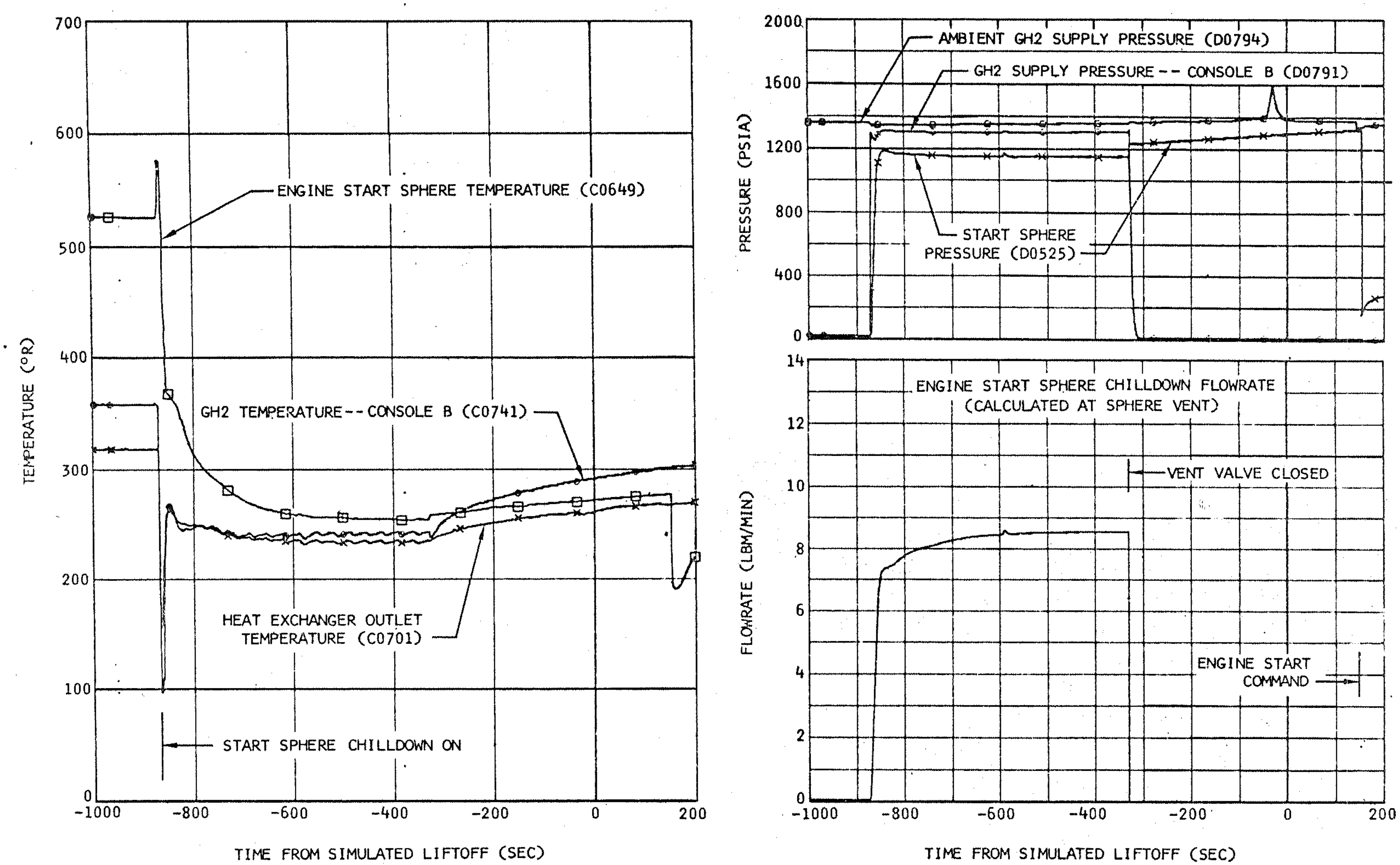

Figure 4-4. GSE Performance During Engine Start Sphere Chilldown and Loading

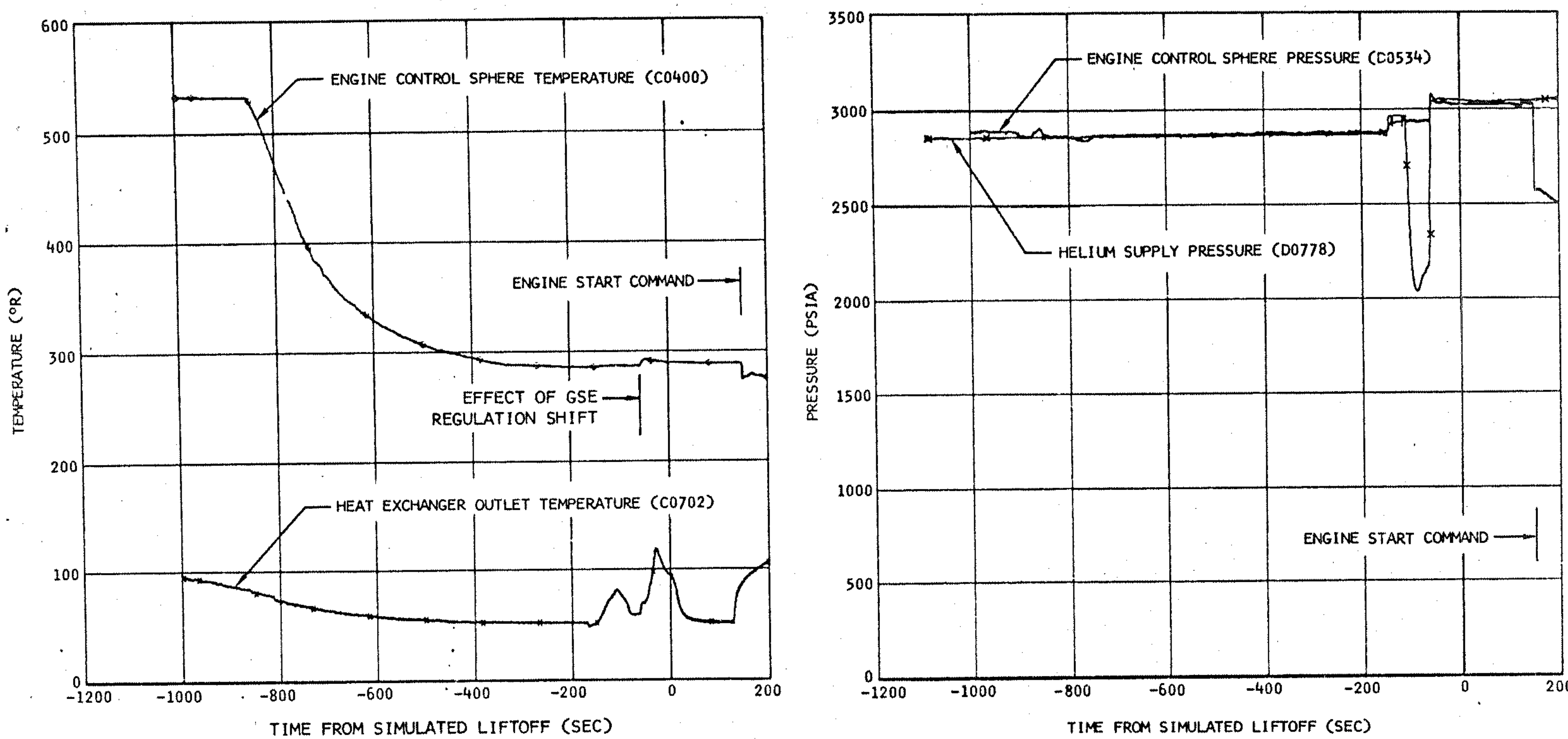

Figure 4-5. GSE Performance During Engine Control Sphere Loading

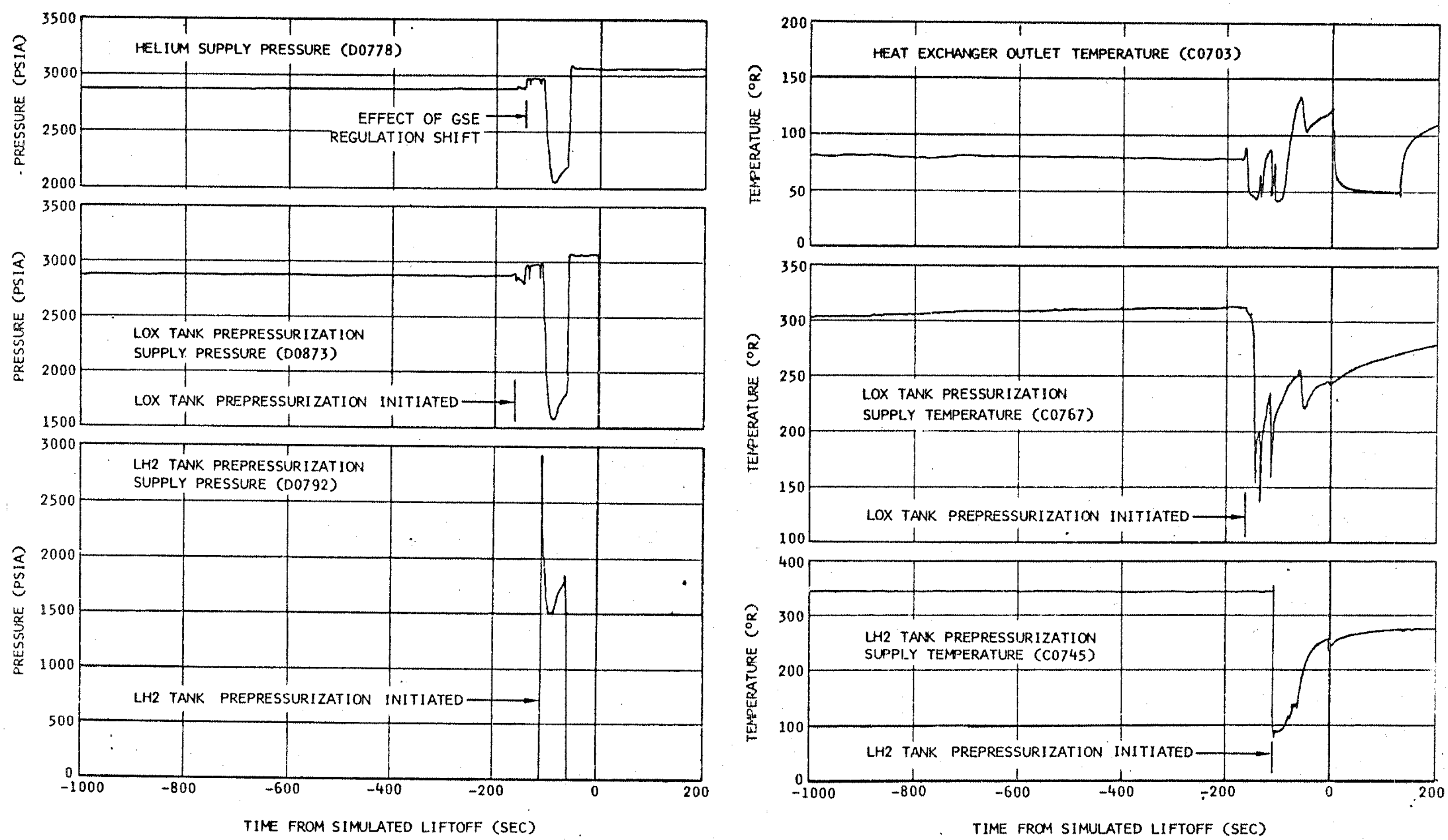

Figure 4-6. GSE Performance During LOX and LH2 Tank Prepressurization

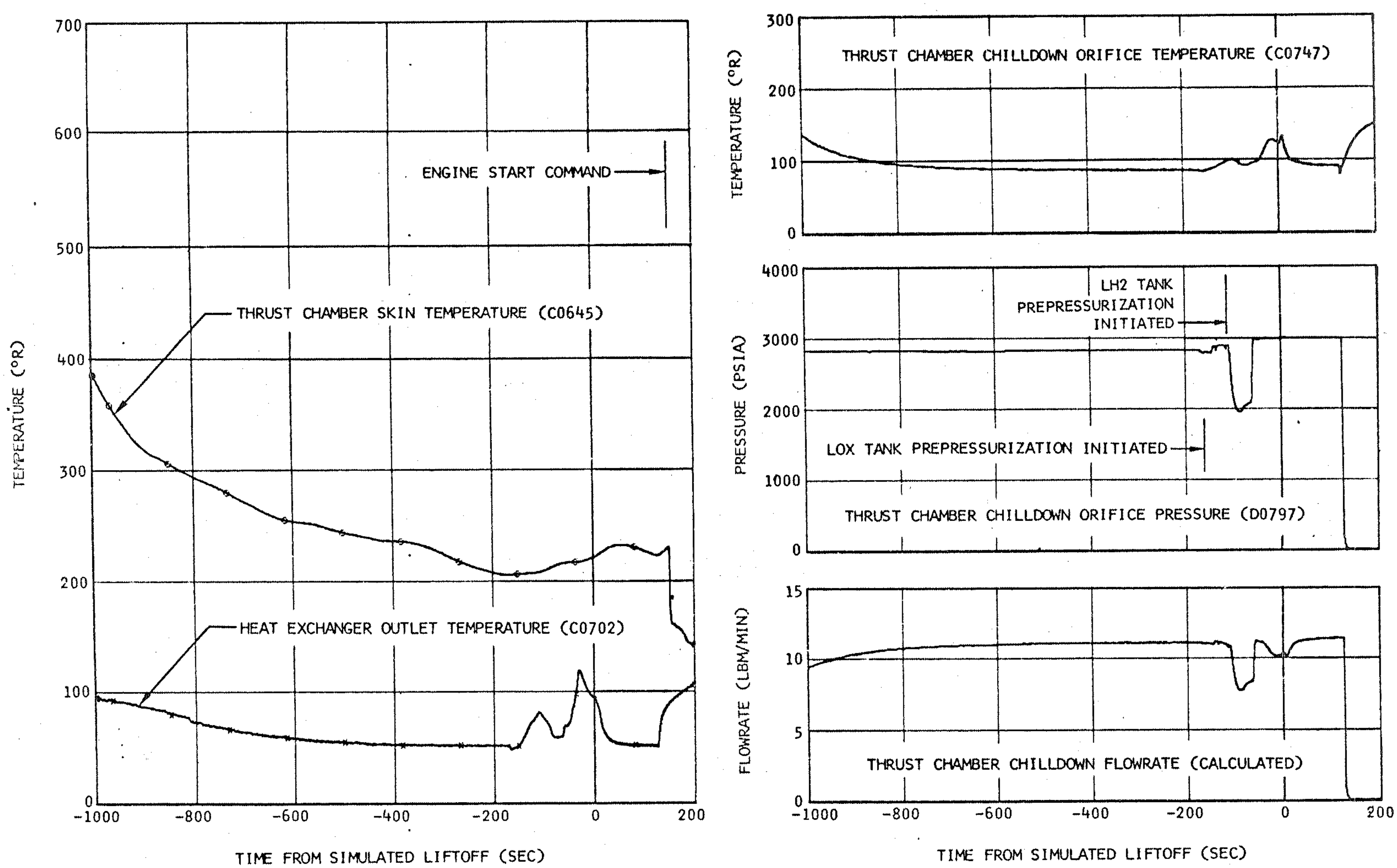

Figure 4-7. GSE Performance During Thrust Chamber Childown

5

SEQUENCE OF EVENTS

5. SEQUENCE OF EVENTS

The S-IVB-209 stage acceptance firing sequence of events is presented in table 5-1. Event times from three data sources are included in the table. These sources were Digital Events Recorder (DER/CAT 57), PCM/FM Sequence (CAT 42), and PCM/FM Digital Tabulation (PCM/TAB/CAT 45). Accuracies of the listed events are as follows:

DATA SOURCE	ACCURACIES
Digital Events Recorder (DER/CAT 57)	+0, -1 ms
PCM/FM	
Discrete Bi-Level (CAT 42)	+0, -9 ms
Digital Tabulation (CAT 45)	
Prime	+0, -9 ms
Submultiplex	+0, -84 ms

TABLE 5-1 (Sheet 1 of 9)
SEQUENCE OF EVENTS

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)		PCM/FM DIGITAL TABULATION (CAT 45)	
		MEAS NO.	TIME (sec)	MEAS NO.	TIME (sec)	MEAS NO.	TIME (sec)
Launch Automatic Sequence Start							
Auxiliary Hydraulic Pump ON	28	K0513	-693.589				
Auxiliary Hydraulic Pump Coast Mode OFF	31	K3890	-694.332				
LOX Chilldown Pump ON	22	K0519	-598.228				
LH2 Chilldown Pump ON	58	K0512	-595.057				
Engine Pump Purge Control Valve Open							
Command	24	K3890	-92.493				
Internal Power Transfer							
Pwr Aft Bus 1 Int Transfer		K0622	-27.371				
Pwr Aft Bus 2 Int Transfer		K0623	-27.118				
Pwr Fwd Bus Int Transfer		K0639	-26.867				
Simulated Liftoff (T_0)*			0.000				
Inflight Cal ON		K3890	91.819				
Inflight Cal OFF		K3890	92.942				
Ullage Rocket Chg ON Cmd	54	K3890	142.600				

*T_0 = 1139:34.000 PDT

TABLE 5-1 (Sheet 2 of 9)
SEQUENCE OF EVENTS

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)		PCM/FM DIGITAL TABULATION (CAT 45)	
		MEAS NO.	TIME (sec)	MEAS NO.	TIME (sec)	MEAS NO.	TIME (sec)
EBW Charge 1-1						M0032	143.3
EBW Charge 1-2						M0033	143.4
EBW Charge 2-1						M0034	143.5
EBW Charge 2-2						M0035	143.3
EBW Charge 3-1						M0036	143.4
EBW Charge 3-2						M0037	143.3
Ullage Rocket Fire Cmd	56	K3890	146.893				
EBW Fire 1-1				K0143	146.929	M0032	146.9
EBW Fire 1-2				K0144	146.929	M0033	146.9
EBW Fire 2-1				K0145	146.937	M0034	146.9
EBW Fire 2-2				K0146	146.937	M0035	146.9
EBW Fire 3-1				K0147	146.937	M0036	146.9
EBW Fire 3-2				K0148	146.937	M0037	146.9
Pre-Valve Open Cmd		K0576	147.560				
LH2 Pre-Valve Open		K0540	150.155	K0111	150.161		
LOX Pre-Valve Open		K0541	150.570	K0109	150.578		

TABLE 5-1 (Sheet 3 of 9)
SEQUENCE OF EVENTS

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)		PCM/FM DIGITAL TABULATION (CAT 45)	
		MEAS NO.	TIME (sec)	MEAS NO.	TIME (sec)	MEAS NO.	TIME (sec)
LH2 Chilldown Pump OFF Cmd	59	K0512	151-574				
Engine Cutoff OFF Cmd	13	K3890	151.372				
Engine Cutoff Command ON (Dropout)		K0522	151.381	K0140	151.387		
Chilldown Pump Discharve Valve Closed Cmd		K0577					
LH2 Chilldown Pump OFF		K0512	151.574				
LOX Chilldown Pump OFF Cmd	23	K3890	151.656				
LOX Chilldown Pump OFF		K0519	151.663				
LOX Chilldown Valve Closed		K0552	151.844				
LH2 Chilldown Valve Closed		K0551	151.556				
Engine Start ON Cmd (ESC)*	9	K3890	151.847				
Thrust Chamber Spark Sys ON		K0454	151.850	K0010	151.851		
Gas Generator Spark ON		K0455	151.850	K0011	151.851		
Helium Control Solenoid Energized		K0531	151.850	K0007	151.851		
Engine Ready Signal OFF		K0530	151.854	K0012	151.920		
Engine Start ON		K0556	151.847				

*ESC = T_0 +151.847 sec

TABLE 5-1 (Sheet 4 of 9)
SEQUENCE OF EVENTS

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)		PCM/FM DIGITAL TABULATION (CAT 45)	
		MEAS NO.	TIME (sec)	MEAS NO.	TIME (sec)	MEAS NO.	TIME (sec)
Ignition Phase Control Solenoid Energ		K0535	151.849	K0006	151.851		
Main Fuel Valve Closed (Dropout)		K0632	151.902	K0119			
Main Fuel Valve Open		K0118		K0118	152.003		
Ignition Detected		K0537	152.044	K0008	152.043		
Engine Start OFF Cmd	27	K3890	152.398				
Engine Start OFF		K0556	152.401				
Start Tank Discharge Valve Close (Dropout)		K0695	153.084	K0123			
Start Tank Discharge Valve Open		K0536	153.379	K0122	153.253		
LOX Tank Flight Pressure System ON Cmd	103	K3890	152.709				
Mainstage Control Solenoid Energized		K0538	153.382	K0005	153.385		
Main Oxidizer Valve Closed (Dropout)		K0633	153.468	K0121			
Gas Generator Valve Closed (Dropout)		K0631	153.482	K0116			
Start Tank Discharge Valve Closed		K0695	153.702	K0122	153.503		

TABLE 5-1 (Sheet 5 of 9)
SEQUENCE OF EVENTS

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)		PCM/FM DIGITAL TABULATION (CAT 45)	
		MEAS NO.	TIME (sec)	MEAS NO.	TIME (sec)	MEAS NO.	TIME (sec)
Gas Generator Valve Open		K0457	153.617	K0117	153.670		
Oxidizer Turbine Bypass Valve Open (Dropout)		K0461	153.631	K0124	153.678		
Oxidizer Turbine Bypass Valve Closed		K0463	153.828	K0125	153.845		
Mainstage Pressure Switch Depress B (Dropout)		K0573		K0159	154.945		
Mainstage Pressure Switch Depress A (Dropout)		K0572		K0158	154.945		
Mainstage OK		K0610	154.907	K0014	154.920		
Engine Burn No. 1 ON Cmd	68	K3890	154.858				
Engine Burn No. 1 ON (LH2 Tnk Step Press Cont Sol)		K0523	154.866				
Main Oxidizer Valve Open		K0459	155.522	K0120	155.586		
Gas Generator Spark System ON (Dropout)		K0455	156.679	K0011	156.684		
Thrust Chamber Spark System ON (Dropout)		K0454	156.680	K0010	156.684		
PU Activate Cmd	5	K3890	158.047				

TABLE 5-1 (Sheet 6 of 9)
SEQUENCE OF EVENTS

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)		PCM/FM DIGITAL TABULATION (CAT 45)	
		MEAS NO.	TIME (sec)	MEAS NO.	TIME (sec)	MEAS NO.	TIME (sec)
PU Activate		K0507	158.052				
Ullage Rocket Jettison Charge ON Cmd	55	K3890	176.078				
EBW Charge 1						M0038	176.8
EBW Charge 2						M0039	176.8
Ullage Rocket Jettison Fire ON Cmd	57	K3890	179.209				
Ullage Jettison Charge Cmd Reset	88	K3890	179.297				
EBW Fire 1				K0149	179.269	M0038	179.3
EBW Fire 2				K0150	179.269	M0039	179.3
Ullage Jettison Fire Cmd Reset	73	K3890	179.384				
Range Safety OFF Enable ON Cmd	85	K3890					
Auxiliary Hydraulic Pump OFF Cmd	29	K3890	337.489				
Auxiliary Hydraulic Pump ON (Dropout)		K0513	337.755				
Auxiliary Hydraulic Pump ON Cmd	28	K3890	384.355				
Auxiliary Hydraulic Pump ON		K0513	384.439				
First Burn Relay OFF Cmd	69	K3890	452.050				

TABLE 5-1 (Sheet 7 of 9)
SEQUENCE OF EVENTS

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)		PCM/FM DIGITAL TABULATION (CAT 45)	
		MEAS NO.	TIME (sec)	MEAS NO.	TIME (sec)	MEAS NO.	TIME (sec)
First Burn Relay OFF		K0523	452.057				
Point Level Sensor ON Cmd	97	K3890					
Non Programmed Engine Cutoff Cmd Cutoff Signal Energized		K0419	610.688				
Ignition Phase Control Solenoid Energized (Dropout)		K0535	610.685	K0006	610.687		
Mainstage Control Solenoid Energized (Dropout)		K0538	610.687	K0005	610.687		
Engine Cutoff ON Cmd	12	K3890					
Engine Cutoff Command ON (ECC)*		K4797.	610.682	K0140	610.698		
Main Oxidizer Valve Open (Dropout)		K0633	610.882	K0120	610.814		
Gas Generator Valve Open (Dropout)		K0631	610.867	K0117	610.731		
Main Fuel Valve Open (Dropout)		K0632	610.992	K0118	610.814		
Engine Pump Purge Control Valve Open Cmd	24	K3890	611.332				
Gas Generator Valve Closed		K0631	610.849	K0116			
Mainstage Pressure Switch B Depress		K0573	610.852	K0159	610.923		

*ECC = T_0 +610.682 sec

TABLE 5-1 (Sheet 8 of 9)
SEQUENCE OF EVENTS

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)		PCM/FM DIGITAL TABULATION (CAT 45)	
		MEAS NO.	TIME (sec)	MEAS NO.	TIME (sec)	MEAS NO.	TIME (sec)
Mainstage Pressure Switch A Depress		K0572	610.857	K0158	610.923		
Main Oxidizer Valve Closed		K0633	610.882	K0121			
Main Fuel Valve Closed		K0632	610.992	K0019			
Fuel Pre-Valve Open (Dropout)		K0540	612.089	K0111	612.139		
Oxidizer Pre-Valve Open (Dropout)		K0541	612.091	K0109	612.139		
Fuel Pre-Valve Closed		K0549	612.421	K0112	612.473		
Oxidizer Pre-Valve Closed		K0550	612.616	K0110	612.639		
Helium Control Solenoid De-energized		K0531		K0007			
Coast Period ON Cmd	79	K3890					
Engine Start OFF Command	27	K3890	612.175				
LH2 Childown Pump OFF Command	59	K3890	612.412				
LOX Childown Pump OFF Command	23	K3890	612.313				
PU Activate OFF Cmd	6	K3890	613.817				
PU Activate OFF		K0507	613.820				
PU Inverter and DC Power OFF Cmd	8	K3890					

TABLE 5-1 (Sheet 9 of 9)
SEQUENCE OF EVENTS

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)		PCM/FM DIGITAL TABULATION (CAT 45)	
		MEAS NO.	TIME (sec)	MEAS NO.	TIME (sec)	MEAS NO.	TIME (sec)
Point Level Sensors Disarm Cmd	98	K3890	613.965				
Ullage Jettison Charge Command Reset	88	K3890	615.445				
First Burn Relay OFF Command	69	K3890	615.533				
Ullage Jettison Fire Command Reset	73	K3890	615.620				

6

ENGINE SYSTEM

6. ENGINE SYSTEM

The S-IVB-209 stage acceptance firing was performed with an uprated (230,000-lbf-thrust) Rocketdyne engine S/N 2083 (figure 6-1) mounted on the stage. The engine was manufactured in the designated configuration baseline for J-2 engines S/N 2077 and subs as described in the Rocketdyne configuration report (R-5788) and contained orifice diameters of 0.276 in. LOX and 0.481 in. LH2 in the gas generator feed system. The engine had a 1-sec start tank discharge valve timer in the engine control circuit and prior to the acceptance firing blank orifices were installed in the start tank refill system to prevent start tank refill. There were no other significant engine modifications affecting engine performance.

6.1 Engine Chilldown and Conditioning

6.1.1 Turbopump Chilldown

Chilldown of the engine LOX and LH2 turbopumps was adequate to provide the conditions required for proper engine start. An analysis of the chilldown operations is presented in paragraphs 7.3 and 8.2.

6.1.2 Thrust Chamber Chilldown

The thrust chamber skin temperature (figure 6-2) was 230 deg R at Engine Start Command (ESC), well within the engine start requirement of 260 $\pm$50 deg R; this resulted in satisfactory start transient buildup characteristics for the LH2 pump (figure 6-3). Data are presented in table 6-1. Further information on the chilldown operation and ground support equipment supply system is presented in section 4.

6.1.3 Engine Control Sphere Chilldown and Loading

Engine control sphere conditioning was adequate (figure 6-4), and all objectives were satisfactorily accomplished. The engine start requirement of 2,000 to 3,450 psia was met. Significant control sphere performance data are presented in table 6-2.

6.1.4 Engine Start Sphere Chilldown and Loading

Chilldown and loading of the engine GH2 start sphere met the requirements for engine start. Start sphere performance data are presented in figure 6-5. The GH2 supply system performance during start sphere chilldown and loading is described in section 4. The sphere warmup rate from sphere pressurization to blowdown was 2.87 deg R/min. Since the S-IVB-209 stage may be utilized in the orbital workshop program, and thus may have to be passivated in orbit, the start sphere was not repressurized during engine operation.

6.2 J-2 Engine Performance Analysis Methods and Instrumentation

Engine performance for the acceptance firing was calculated by use of computer programs AA89, G105-1, and F823-1. Computer program PA49 presents the average performance results. Computer program PA53 was used to compute start and cutoff transient engine performance. A description of the operation and a comparison of the results of each program is presented in table 6-3. Data inputs to the computer programs with the applicable biases are shown in table 6-4.

6.3 J-2 Engine Performance

The engine performance was satisfactory. Plots of selected data showing engine characteristics are presented in figures 6-6 through 6-11. The engine propellant inlet conditions are presented in sections 7 and 8.

The engine performance levels were comparable, within the run-to-run deviations, to the levels established during the Rocketdyne stage acceptance firing series and the stage acceptance firing prediction. The performance profiles determined by the programs discussed in paragraph 6.2 are shown in figure 6-12; the composite values which constitute the final engine performance values are shown in table 6-5.

Flow integral mass analysis indicates that 189,949 lbm of LOX and 36,856 lbm of LH2 were consumed between Engine Start Command and Engine Cutoff Command (ECC). This value of propellant consumption will be further refined and presented in the flow integral cryogenic calibration report on the S-IVB-209 stage propellant utilization system. The analysis also indicates that the overall stage average thrust from the 90 percent performance level (ESC +3.799 sec) to engine cutoff (ESC +458.836 sec) was 212,412 lbf. The average mixture ratio and specific impulse were 5.192 and 426.8 sec, respectively, for the same time period. The variation of specific impulse with mixture ratio is shown in figure 6-13. The total impulse generated from Engine Start Command to Engine Cutoff Command was 97.67 X 10^6 lbf-sec. Extrapolation of the propellant residuals as indicated by the point level sensors (2,311 lbm of LOX, 1,366 lbm of LH2) indicates that a LOX depletion cutoff would have occurred at ECC +5.148 sec. In that time, an additional 937,591 lbf-sec impulse would have been generated, making the total stage potential impulse from Engine Start Command to depletion cutoff 98.61 X 10^6 lbf-sec, as compared to the predicted value of 98.53 X 10^6 lbf-sec. The 0.08 percent deviation is within the predicted accuracy of approximately 1 percent. The 4.228 sec difference between the actual and predicted times is also within the prediction accuracy.

6.3.1 Start Transient

The J-2 engine start transient was satisfactory. A summary of engine performance is presented in the following table:

	Acceptance Firing	Log Book
Time to 90 percent performance level (sec)	3.799	3.48
Start Tank Discharge Valve Command (sec)	ESC +1.083	ESC +1.0
Thrust rise time (sec)	2.439	2.00
Total impulse (lbf-sec)	186,220	159,926*
Maximum rate of thrust increase (lbf/sec)	6,370	40,000**

* Based on stabilized thrust at null PU and standard altitude conditions (test No. 313-082)

** Maximum allowable

Thrust buildup to the 90 percent performance level (627 psia thrust chamber pressure for the uprated engine) was within the maximum and minimum thrust bands. The deviation in total impulse (log book) is due to longer thrust rise time (time from first indication of thrust to the 90 percent performance level) during the acceptance firing. The total impulse accumulated during the start transient is shown in figure 6-14. Figure 6-15 shows the thrust chamber pressure during start transient and the thrust buildup to the 90 percent performance level for the acceptance firing as determined by computer program PA53. As expected, thrust overshoot during the start transient did not occur. No correction was made on acceptance firing data for main LOX valve skin temperature, as these data are not available.

6.3.2 Steady-State Performance

Satisfactory performance of the J-2 engine was demonstrated throughout the steady-state portion of the engine burn. No evidence of an engine performance shift was found in any of the engine instrumentation.

Table 6-5 compares the overall average performance values during steady-state operation with the predicted performance values. The S-IVB-209 stage utilized an uprated (230,000 lbf thrust) J-2 engine which explains the high performance values. The deviation between the PU valve cutback time prediction and the actual PU valve cutback time is discussed in section 10.

Engine thrust variations occurring during the acceptance firing are presented in table 6-6. These thrust variations are compared to the predicted acceptance firing thrust history and the Contract End Item (CEI) thrust variation limits for flight. The CEI limits do not apply to acceptance firing performance and are presented for reference only. The thrust variations will be modified by flight effects on stage operation.

Figure 6-16 presents expanded thrust plots illustrating thrust variations noted during the following phases of engine operations:

a. Hardover, or maximum engine mixture ratio operation (EMR = 5.5)

   The thrust variations during hardover operation were within the CEI limits for normal engine operation. Normal operating thrust variations during this period of engine burn are caused by stabilization of the engine and by stage perturbations, including the effects of variations in propellant supply environmental condition, and propellant tank pressurization requirements.

b. Transient from PU valve cutback +65 sec to ECC -70 sec

Thrust variations during the transient period from PU valve cutback +65 sec to ECC -70 sec were within the CEI limits for normal engine operation. The thrust variations during this period were caused by stabilization of the engine after cutback and can be directly linked to movements of the PU valve.

c. Final 70 sec of burn

Thrust variations during the final 70 sec of engine burntime were within the CEI limits for normal engine operation. These thrust variations were mainly due to movements of the PU valve. These movements will be modified somewhat by flight effects on stage performance and by improved flight calibration of the PU system.

6.3.3 Cutoff Transient

The time between engine cutoff, as received at the J-2 engine and monitored by event measurement K0539 (time of cutoff = T_0 +610.683 sec), and thrust decrease to 11,500 lbf was within the maximum allowable time of 800 ms for the acceptance firing as shown in the following table:

	Acceptance Firing	Log Book	Allowable
Thrust decrease to 11,500 lbf (ms)	370	359	340 $\pm$30
Total impulse (lbf-sec)	34,636*	35,411**	34,100 $\pm$1,300

* PU valve at -13.5 deg

** PU valve at null position, standard altitude conditions, includes -2,400 lbf-sec correction for time bias due to inherent electronic circuitry system delays

The performance values presented are in satisfactory agreement with the log book and the Rocketdyne J-2 Engine Manual No. R-3825-1. The stage acceptance firing does not include a correction for main LOX valve skin temperature deviation from 0 deg F or PU valve deviation from null position. Figures 6-17 and 6-18 present the data for the accumulated cutoff impulse, thrust chamber pressure cutoff transient, and the cutoff thrust to the 11,500 lbf level, as calculated by computer program PA53.

6.4 Engine Sequencing

The engine sequencing was satisfactory throughout the acceptance firing and compatible with the engine logic and the acceptance firing test plan. Table 6-7 and figure 6-19 illustrate the event times recorded during the acceptance firing. The measured values are compared with nominal or log book values. Most of the disagreements between measured and log book values are insignificant and may be ascribed to sampling rate errors or effects of the liquids that are present during the acceptance firing but absent during log book testing. The opening time of the gas generator valve was slower than nominal, but this caused no ill effects to the firing.

6.5 Component Operation

All components on the J-2 engine (S/N 2083) performed satisfactorily during the S-IVB-209 acceptance firing. The main LOX valve opened satisfactorily. The opening time data were as follows:

Item	Specification	Actual
First stage travel (ms)	50 ±25	55
First plateau (ms)	510 ±70	533
Second stage travel (ms)	1,825 ±75	1,804
Total time (ms)	2,385 ±170	2,392

All times were within specifications, indicating nominal main LOX valve performance during valve opening. The valve closing time was 170 ms which was approximately 35 ms longer than the maximum specified; however, this did not contribute to any significant increase in cutoff transient impulse.

The performance of the pumps, turbines, and gas generator were satisfactory. Data indicative of the performance of these components are shown in figures 6-9, 6-10, and 6-11, respectively. PU valve performance was also satisfactory and is discussed in section 10.

The engine-driven hydraulic pump performed satisfactorily during the acceptance firing. The gimbal program was conducted between approximately ESC +69 and ESC +125 sec. Calculation made during the gimbal program showed the following hydraulic pump performance.

Time from ESC (sec)	Horsepower Required (hp)
80	6.4
101	6.2

This is point function data only and no extrapolations are to be made between the time points given. For times prior to ESC +69 sec and after ESC +125 sec, the required horsepower was 4.8.

6.6 Engine Vibration

Five vibration measurements were monitored on the engine which included one at the LOX turbopump, one at the LH2 turbopump, and three on the combustion chamber dome. All measurements provided usable data and are shown as power spectral density plots (figure 6-20). The vibration levels at these locations were comparable to those measured on past acceptance firings.

TABLE 6-1
THRUST CHAMBER CHILLDOWN

PARAMETER	S-IVB-209	S-IVB-208	S-IVB-207
Engine Start Requirement (°R)	260 ±50	260 ±50	260 ±50
Thrust Chamber Chilldown Initiated (sec)*	-1,200	-1,201	-1,200
Thrust Chamber Chilldown Terminated (sec)*	128	127	127
Thrust Chamber Skin Temperature at End of Chilldown (°R)	223	227	240
Thrust Chamber Temperature at Engine Start (°R)	230	230	250

*Time from simulated liftoff (T_0)

TABLE 6-2
ENGINE CONTROL SPHERE PERFORMANCE

PARAMETER	TEMPERATURE (°R)			PRESSURE (psia)			MASS (lbm)		
	S-IVB 209	S-IVB 208	S-IVB 207	S-IVB 209	S-IVB 208	S-IVB 207	S-IVB 209	S-IVB 208	S-IVB 207
Engine Start Requirement	None	290 ±30		2,000 to 3,450	2,800 to 3,450		--	--	--
Engine Start Command	289	270	296	2,877	3,144	3,264	1.90	2.08	1.98
Engine Cutoff	*271	229	252	2,243	2,139	2,187	1.56	1.73	1.61
Total Helium Usage	--	--	--	--	--	--	0.34	0.35	0.37

* The start sphere was not recharged.

TABLE 6-3
COMPARISON OF COMPUTER PROGRAM RESULTS

PROGRAM	INPUT	METHOD	RESULTS
AA89	LOX and LH2 pump inlet pressures and temperatures, PU valve position, and engine tag values	Influence equations relate nominal inlet conditions to nominal performance. Using actual inlet conditions, PU valve position and engine tag values, the actual performance is simulated.	F = 213,739 lbf $\dot{W}_T$ = 501.22 lbm/sec I_{sp} = 426.59 sec MR = 5.203
G105 Mode 3	LOX and LH2 flowmeters, pump discharge pressures and temperatures, chamber pressures, chamber thrust area	Flowrates are computed from flowmeter data and propellant densities. The C_F is determined from equation $C_F = f\ (P_c, MR)$ and thrust is calculated from equation $F = C_F A_t P_c$.	F = 211,812 lbf $\dot{W}_T$ = 498.05 lbm/sec I_{sp} = 425.39 sec MR = 5.206
F823 Mode 1	Thrust chamber pressure, gas generator pressure, fuel injection temperature, fuel pump discharge temperature, fuel turbine inlet temperature	Total flows of the thrust chamber and gas generator are calculated as a function of respective chamber pressures. Mixture ratio of the chamber is calculated as a function of temperature rise of the fuel in the cooling jacket, and mixture ratio of the GG is calculated as a function of turbine inlet temperature. Thrust is calculated from the equation $F = C_F A_t P_c$.	F = 211,686 lbf $\dot{W}_T$ = 494.48 lbm/sec I_{sp} = 428.30 sec MR = 5.166
PA53	Thrust chamber pressure, chamber throat area	The C_F is computed from equation $C_F = \ (P_c)$ and thrust is computed from equation $F = C_F A_t P_c$. The impulse is determined from integrated thrust.	Refer to paragraphs 6.3.1 and 6.3.3.

TABLE 6-4 (Sheet 1 of 2)
DATA INPUTS TO COMPUTER PROGRAMS

PARAMETER	PROGRAM	SELECTION	REASON	BIAS	REASON
Chamber Pressure	G105-1, F823-1	D0524 (H/W)	Appeared to be in better agreement with engine log book data	-0.28	Psig +14.72 = psia $P_c$meas -15 = $P_c$act (Rocketdyne estimation of P_c purge effect)
	PA53	D0001 (T/M)	High sampling rate produced more realistic transient	98.11 Percent	Adjusts P_c so that at ESC, P_c Prog = $P_c$input; at ESC +60 sec, P_c Prog = $P_c$input -15 psi
LH2 Injection Temp	F823-1	C0646 (H/W)	Only one available	0	
LH2 Pump Disch Press	G105-1	D0008 (T/M)	Agreed with engine log book data	0	
LH2 Pump Disch Temp	G105-1 F823-1	C0134 (T/M)	T/M & H/W essentially the same. Used T/M	0	
LOX Pump Disch Press	G105-1	D0009 (T/M)	Less noisy	0	
LOX Pump Disch Temp	G105-1	C0648 (H/W)	Less noisy	0	
LH2 Flowrate	G105-1	F0002 (T/M)	Less noisy	-41.82 gpm	Agree with actual pip count
LOX Flowrate	G105-1	F0001 (T/M)	T/M & H/W essentially the same. Used T/M	+1.94 gpm	Agree with actual pip count

H/W - Hardwire

T/M - Telemetry

TABLE 6-4 (Sheet 2 of 2)
DATA INPUTS TO COMPUTER PROGRAMS

PARAMETER	PROGRAM	SELECTION	REASON	BIAS	REASON
LH2 Pump Inlet Press	AA89	D0536 (H/W)	T/M transducer affected by pump childown	+15.917	Psig +14.72 = psia. Add 1.197 for dynamic head
LH2 Pump Inlet Temp	AA89	C0003 (T/M)	T/M & H/W essentially the same. Used T/M	-0.3	0 adjustment
LOX Pump Inlet Press	AA89	D0537 (H/W)	Less noisy	+17.20	Psig +14.72 = psig. Add 2.48 for dynamic head
LOX Pump Inlet Temp	AA89	C0004 (T/M)	T/M & H/W essentially the same. Used T/M	0	
Gas Generator P_c	F823	D0010 (T/M)	Less Noisy	0	
LH2 Turbine Inlet Temp	F823	C0001 (T/M)	H/W not available	0	
PU Valve Position	AA89	G0010 (T/M)	T/M & H/W essentially the same. Used T/M	0	

H/W - Hardwire

T/M - Telemetry

TABLE 6-5
ENGINE PERFORMANCE

PARAMETER	CLOSED PU VALVE OPERATION			REFERENCE MIXTURE RATIO OPERATION			OVERALL PERFORMANCE		
	ACTUAL	PREDICTED	PERCENT DEVIATION	ACTUAL	PREDICTED	PERCENT DEVIATION	ACTUAL	PREDICTED	PERCENT DEVIATION
Thrust (lbf)	229,885	230,756	0.4	186,683	186,988	0.2	212,412	214,300	0.9
Total flowrate (lbf/sec)	540.43	542.70	0.4	435.33	435.77	0.1	497.92	502.46	0.9
LOX flowrate (lbm/sec)	457.76	460.06	0.5	358.88	359.70	0.2	417.69	422.28	1.1
LH2 flowrate (lbm/sec)	82.67	82.64	0.04	76.45	76.03	0.6	80.23	80.18	0.1
Engine mixture ratio	5.537	5.567	0.5	4.694	4.731	0.8	5.192	5.251	1.1
Specific impulse (sec)	425.37	425.20	0.04	428.84	429.13	0.1	426.76	426.68	0.02

TABLE 6-6
ENGINE THRUST VARIATIONS

TIME PERIOD	LIMITS	HARDOVER	TRANSIENT FROM PU VALVE CUTBACK +65 sec TO ECC -70 sec	FINAL 70 sec OF BURN
Variation in mean thrust level (lbf) or thrust band centerline variation at ECC -70 sec (lbf)	Allowable*	±4000	+6000 -5000	±6000
	Actual	830	790	500
	Predicted	--	--	--
Oscillations about mean thrust level (lbf) or thrust variation band (lbf)	Allowable	±2500	±7500	±3000
	Actual	±1090	±1710	±490
	Predicted	±740	±325	±390
Rate of change of thrust (lbf/sec)	Allowable	±500	±500	±500
	Actual	+435	-370	+87
	Predicted	+35	+29	+40
Thrust acceleration (lbf/sec)	Allowable	±125	±350	±350
	Actual	+108	+32.1	-16.8
	Predicted	+6	+2.7	4.5
Thrust band slope (lbf/sec)	Allowable	--	--	+115 -60
	Actual	--	--	+1.0
	Predicted	--	--	+6.5
Variation of thrust band slope about nominal (lbf/sec)	Allowable	--	--	±35
	Actual	--	--	5.5
	Predicted	--	--	--

* Allowable limits are quoted from Specification Change Notice No. 7, dated 1 June 1967, and assume a nominal PU cutback at ESC +250 sec.

TABLE 6-7 (Sheet 1 of 6)
ENGINE SEQUENCE

CONTROL EVENTS		CONTINGENT EVENTS		NOMINAL TIME FROM SPECIFIED REFERENCE	ACTUAL TIME (ms)	
MEAS NO.	EVENT AND COMMENT	MEAS NO.	EVENT AND COMMENT		FROM ESC	FROM SPECIFIED REFERENCE
K0021 (K0021)	*Engine Start Command P/U			0	0	0
		K0007 (K0531)	Helium Control Solenoid Engr P/U	Within 10 ms of K0021	3	3
		K0010 (K0454)	Thrust Chamber Spark on P/U	Within 10 ms of K0021	3	3
		K0011 (K0455)	Gas Generator Spark on P/U	Within 10 ms of K0021	3	3
		K0006 (K0535)	Ignition Phase Control Solenoid Engr P/U	Within 20 ms of K0021	2	2
		K0012 (K0530)	Engine Ready D/O	Within 20 ms of K0006	7	5
		K0126 (K0558)	LOX Bleed Valve Closed P/U	Within 130 ms of K0007	62	59
		K0127 (K0557)	LH2 Bleed Valve Closed P/U	Within 130 ms of K0007	49	46
		K0020 (K0627)	ASI LOX Valve Open P/U	Within 20 ms of K0006	39	37

(K0XXX) Actual number from acceptance firing event recorder.

*Engine ready and stage separation signals (or simulation) are required before this command will be executed. This command also actuates a 640 ±30 ms timer which controls energizing of the start tank discharge solenoid valve (K0096).

TABLE 6-7 (Sheet 2 of 6)
ENGINE SEQUENCE

CONTROL EVENTS		CONTINGENT EVENTS		NOMINAL TIME FROM SPECIFIED REFERENCE	ACTUAL TIME (ms)	
MEAS NO.	EVENT AND COMMENT	MEAS NO.	EVENT AND COMMENT		FROM ESC	FROM SPECIFIED REFERENCE
		K0119 (G0506)	Main Fuel Valve Closed	60 ±30 ms from K0006	39	37
		K0118 (G0506)	Main Fuel Valve Open P/U	80 ±50 ms from K0119	121	82
K0008 (K0537)	*Ignition Detected			Within 250 ms of K0021 P/U	197	197
K0021 (K0021)	**Engine Start Command D/O			Approx 200 ms from K0021 P/U	219	219
K0096 (K0536)	***Start Tank Disc Control Solenoid Engr			1,000 ±40 ms from K0021	1,083	1,083
		K0123 (G0508)	Start Tank Disc Valve Closed D/O	100 ±20 ms from K0096	1,216	133
		K0122 (G0508)	Start Tank Disc Valve Open P/U	105 ±20 ms from K0123	1,353	137
K0005 (K0538)	Mainstage Control Solenoid Engr			450 ±30 ms from K0096	1,535	452

*This signal must be received within 1,110 ±60 ms of K0021 P/U or cutoff will be initiated.

**This signal drops out after a time sufficient to lock in the engine electrical.

***An indication of fuel injection temperature of -150 ±40 deg F (or simulation) is required before this command will be executed. This command also actuates a 450 ±30 ms timer which controls the start of mainstage.

(K0XXX) Actual number from acceptance firing event recorder.

TABLE 6-7 (Sheet 3 of 6)
ENGINE SEQUENCE

CONTROL EVENTS		CONTINGENT EVENTS		NOMINAL TIME FROM SPECIFIED REFERENCE	ACTUAL TIME (ms)	
MEAS NO.	EVENT AND COMMENT	MEAS NO.	EVENT AND COMMENT		FROM ESC	FROM SPECIFIED REFERENCE
		K0096 (K0536)	Start Tank Disc Control Solenoid Engr D/O	450 ±30 ms from K0096	1,532	449
		K0121 (G0507)	Main LOX Valve Closed D/O	60 ±30 ms from K0005	1,580	45
		K0116 (G0509)	Gas Generator Valve LOX side first motion	140 ±10 ms from K0005	1,710	5
		K0122 (G0508)	Start Tank Disc Valve Open D/O	95 ±20 ms from K0096 D/O	1,617	534
		K0117 (G0509)	Gas Generator Valve Open P/U	50 ±30 ms from K0116	1,811	151
		K0124 (G0510)	LOX Turbine Bypass Valve Open D/O		1,720	
			LOX Turbine Bypass Valve 80% Closed	400^{+150}_{-50} ms from K0122	1,977	360
		K0123 (G0508)	Start Tank Disc Valve Closed P/U	250 ±40 ms from K0122	1,884	267
		K0125 (G0510)	*LOX Turbine Bypass Valve Closed P/U		2,028	
K0158 (K0572)	Mainstage Press Switch No. 1 Depress D/O				3,061	

*Within 5,000 ms of K0005 (Normally = 500 ms)

(K0XXX) Actual number from acceptance firing event recorder.

TABLE 6-7 (Sheet 4 of 6)
ENGINE SEQUENCE

CONTROL EVENTS		CONTINGENT EVENTS		NOMINAL TIME FROM SPECIFIED REFERENCE	ACTUAL TIME (ms)	
MEAS NO.	EVENT AND COMMENT	MEAS NO.	EVENT AND COMMENT		FROM ESC	FROM SPECIFIED REFERENCE
K0159 (K0573)	Mainstage Press Switch No. 2 Depress D/O				3,069	
K0191 (K0610)	*Mainstage OK				3,060	
		K0120 (G0507)	Main LOX Valve Open P/U	2,435 $\pm$35 ms from K0005	3,965	2,430
		K0010 (K0454)	Thrust Chamber Spark on D/O	3,300 $\pm$200 ms from K0005 P/U	4,833	3,298
		K0011 (K0455)	Gas Generator Spark On D/O	3,300 $\pm$200 ms from K0005 P/U	4,832	3,297
K0507 CSS-22	PU Activate Switch P/U				6,205	
K0013 (K0539)	Engine Cutoff P/U (New Time Reference)			0	0	0
		K0005 (K0538)	Mainstage Control Solenoid Engr D/O	Within 10 ms of K0013	4	4
		K0006 (K0535)	Ignition Phase Control Solenoid Engr D/O	Within 10 ms of K0013	2	2
		K0020 (K0627)	ASI LOX Valve Open D/O		22	
		K0120 (G0507)	Main Oxidizer Valve Open D/O	50 $\pm$15 ms from K0005	75	71
		K0117 (G0509)	Gas Generator Valve Open D/O	75^{+25}_{-35} ms from K0006	23	21

*One of these signals must be received within 4,410 $\pm$260 ms from K0021 P/U, or cutoff will be initiated. Signal occurs when LOX injection pressure is 500 $\pm$30 psig.

(KOXXX) Actual number from acceptance firing event recorder.

TABLE 6-7 (Sheet 5 of 6)
ENGINE SEQUENCE

CONTROL EVENTS		CONTINGENT EVENTS		NOMINAL TIME FROM SPECIFIED REFERENCE	ACTUAL TIME (ms)	
MEAS NO.	EVENT AND COMMENT	MEAS NO.	EVENT AND COMMENT		FROM ESC	FROM SPECIFIED REFERENCE
		K0118 (G0506)	Main Fuel Valve Open D/O	90 ±25 ms from K0006	100	98
		K0121 (G0507)	Main Oxidizer Valve Closed P/U	120 ±15 ms from K0120	240	165
		K0116 (G0509)	Gas Generator Valve Closed P/U	500 ms from K0006	385	383
		K0119 (G0506)	Main Fuel Valve Closed	225 ±25 ms from K0118	377	277
K0158 (K0572)	*Mainstage Press Switch A Depress P/U				174	
K0159 (K0573)	Mainstage Press Switch B Depress P/U				169	
K0191 (K0610)	Mainstage OK D/O				174	
K0007 (K0531)	Helium Control Solenoid Enrg D/O			1,000 ±110 ms from K0013	1,008	1,008

*Signal drops out when pressure reaches 425 ±25 psig

(K0XXX) Actual number from acceptance firing event recorder.

TABLE 6-7 (Sheet 6 of 6)
ENGINE SEQUENCE

CONTROL EVENT		CONTINGENT EVENTS		NOMINAL TIME FROM SPECIFIED REFERENCE	ACTUAL TIME (ms)	
MEAS NO.	EVENT AND COMMENT	MEAS NO.	EVENT AND COMMENT		FROM ESC	FROM SPECIFIED REFERENCE
SS-22 (K0507)	PU Activate Switch D/O			N/A	3,137	
		K0125 (G0510)	Oxidizer Turbine Bypass Valve Closed D/O		220	
		K0124 (G0510)	Oxidizer Turbine Bypass Valve Open P/U	10,000 ms from K0005	847	843
K0126 (K0558)	LOX Bleed Valve Closed D/O			30,000 ms from K0005	7,210	7,206
K0127 (K0557)	LH2 Bleed Valve Closed D/O			30,000 ms from K0005	9,111	9,107

(KOXXX) Actual number from acceptance firing event recorder.

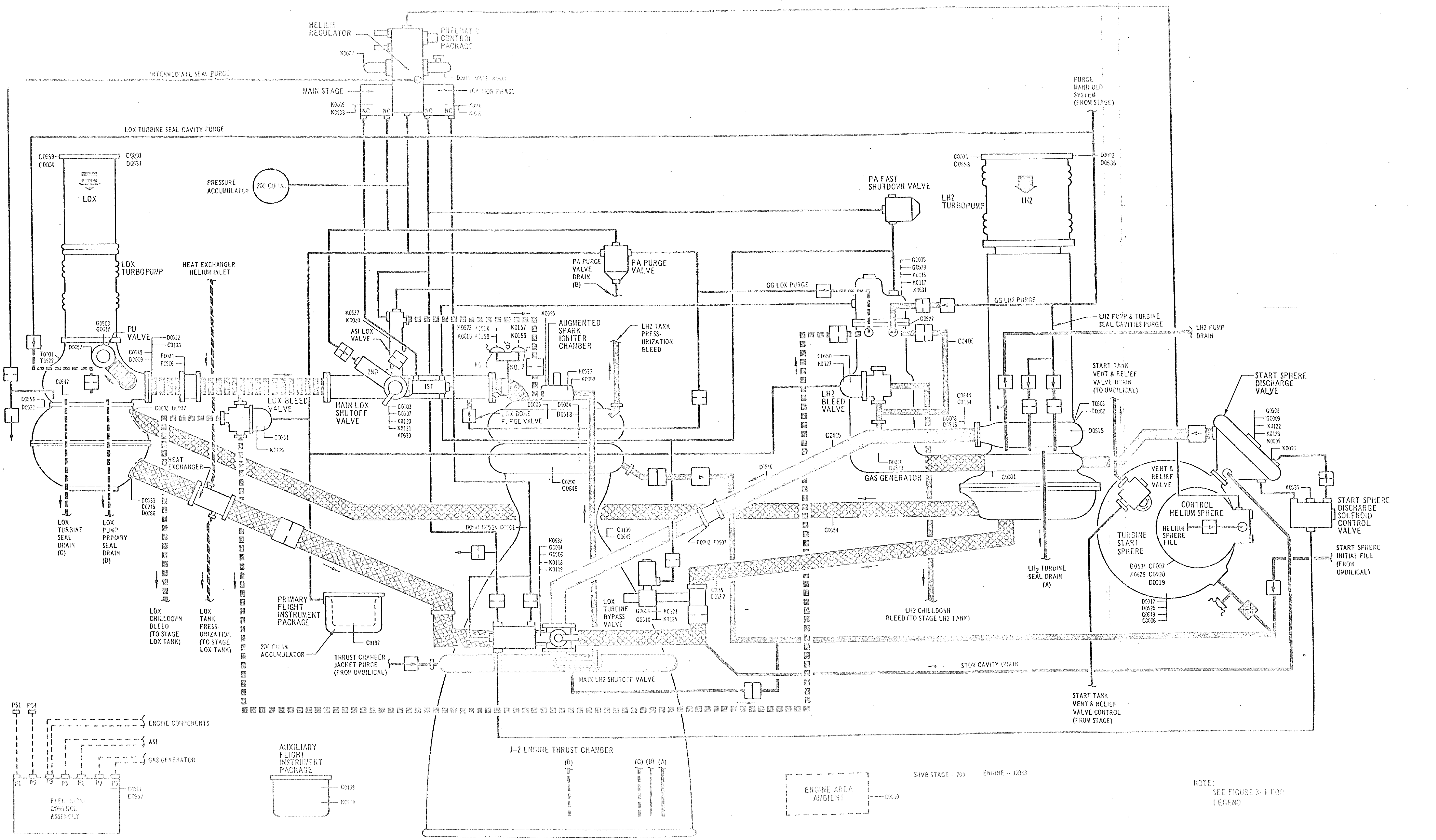

Figure 6-1. J-2 Engine System and Instrumentation

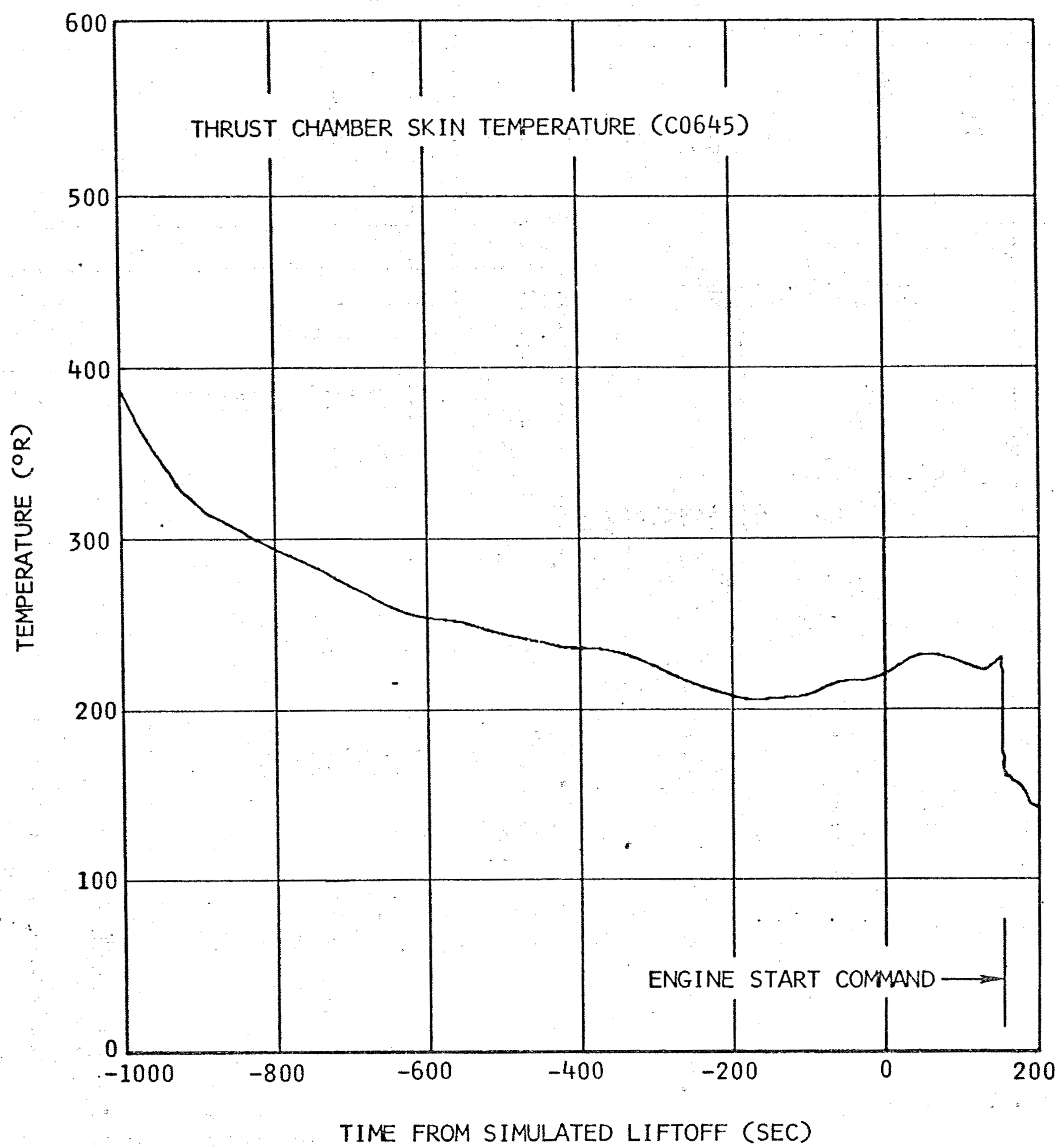

Figure 6-2. Thrust Chamber Chilldown

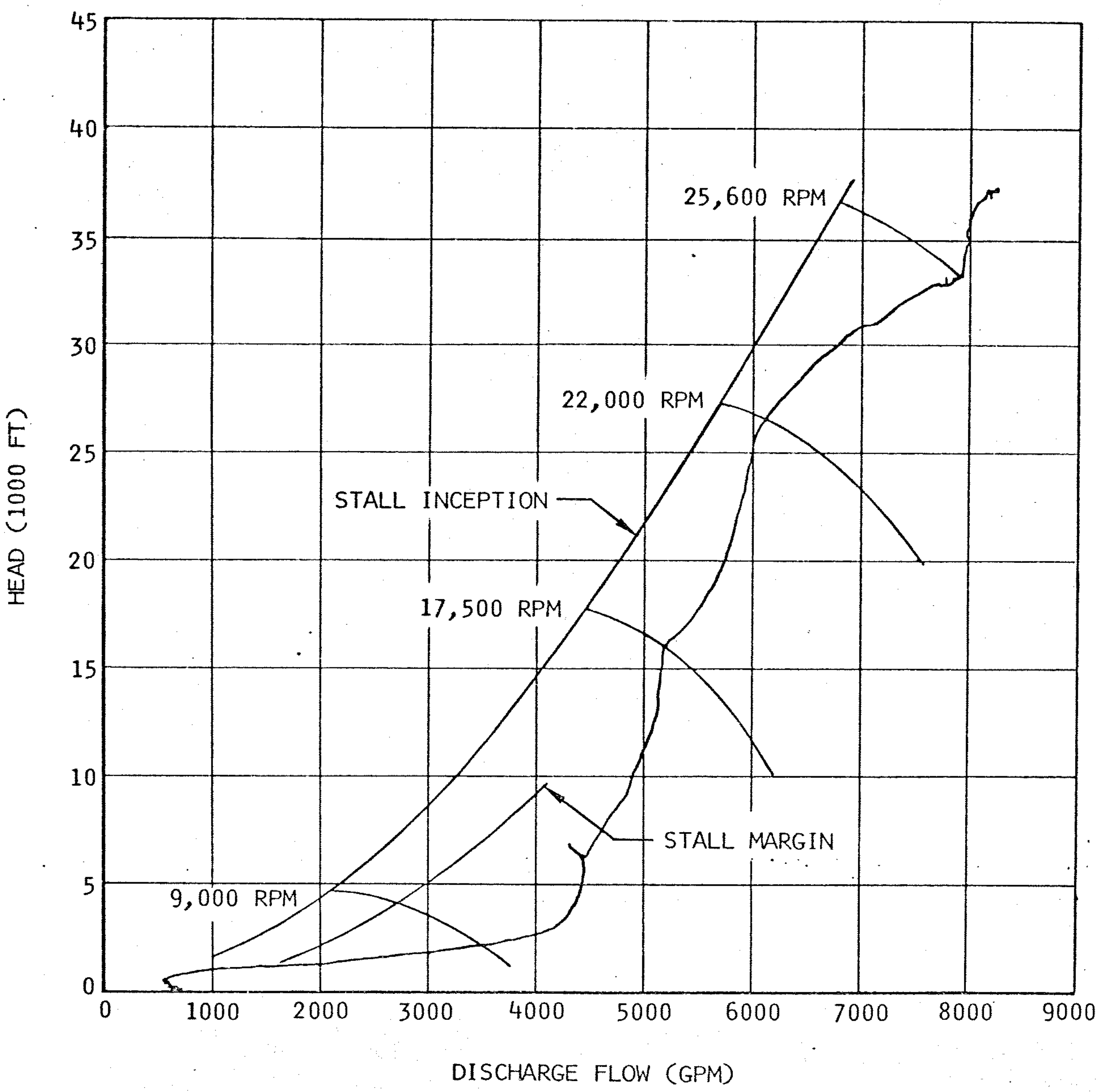

Figure 6-3. LH2 Pump Performance During Engine Start

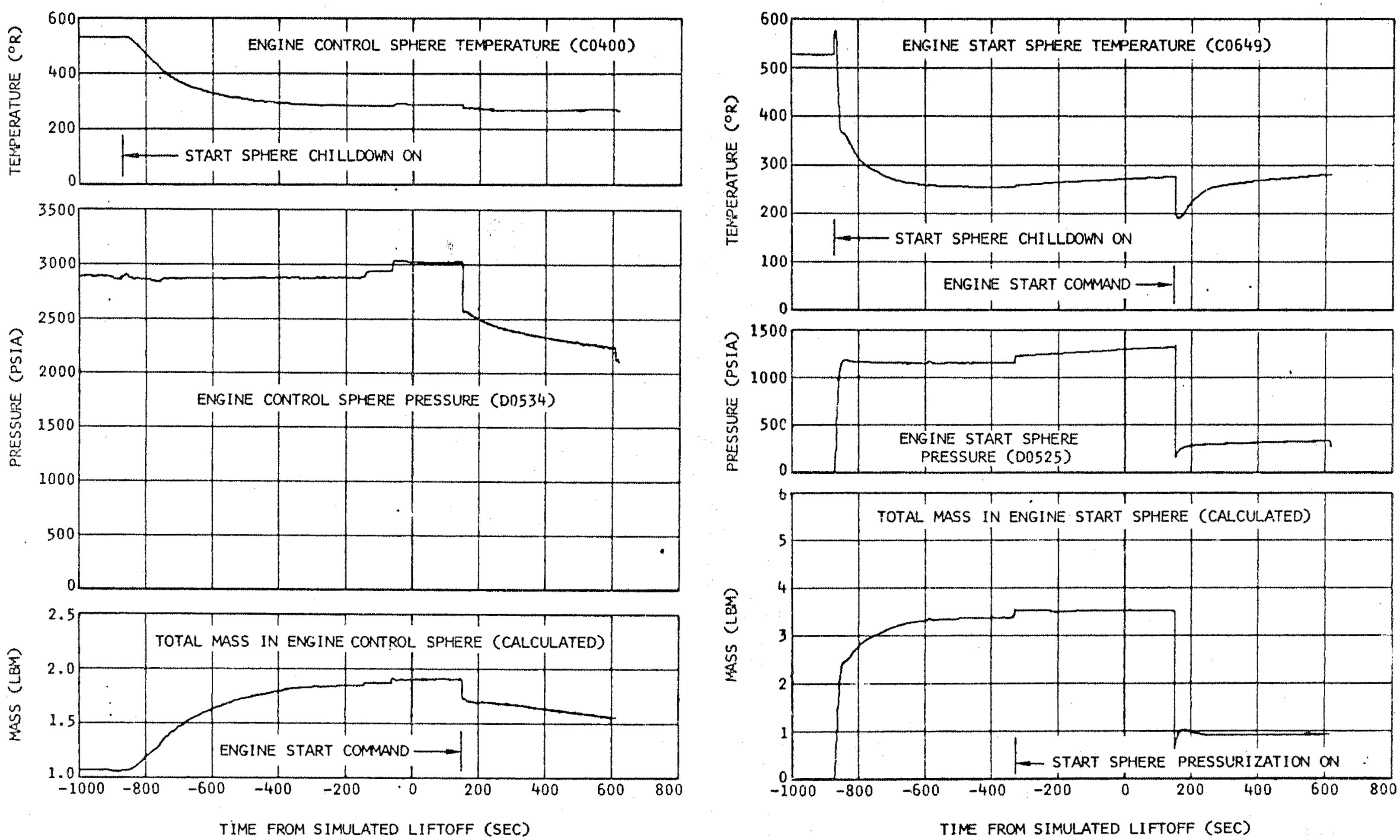

Figure 6-4. Engine Start and Control Sphere Performance

PARAMETER	TEMPERATURE (°R)			PRESSURE (PSIA)			MASS (LBM)		
	209	208	207	209	208	207	209	208	207
ENGINE START REQUIREMENT	SEE START REGION			SEE START REGION					
ENGINE START COMMAND							3.53	3.83	3.32
AFTER START SPHERE BLOWDOWN	194	168	200	152	160	169	0.64	0.72	0.66
ENGINE CUTOFF	281*	225	205	330*	1362	1300	0.92*	4.48	3.85
TOTAL GH2 USAGE DURING START							2.89	3.11	2.66

* FOR S-IVB-209 ACCEPTANCE THE START SPHERE WAS NOT RECHARGED. SEE PARAGRAPH 6.1.4.

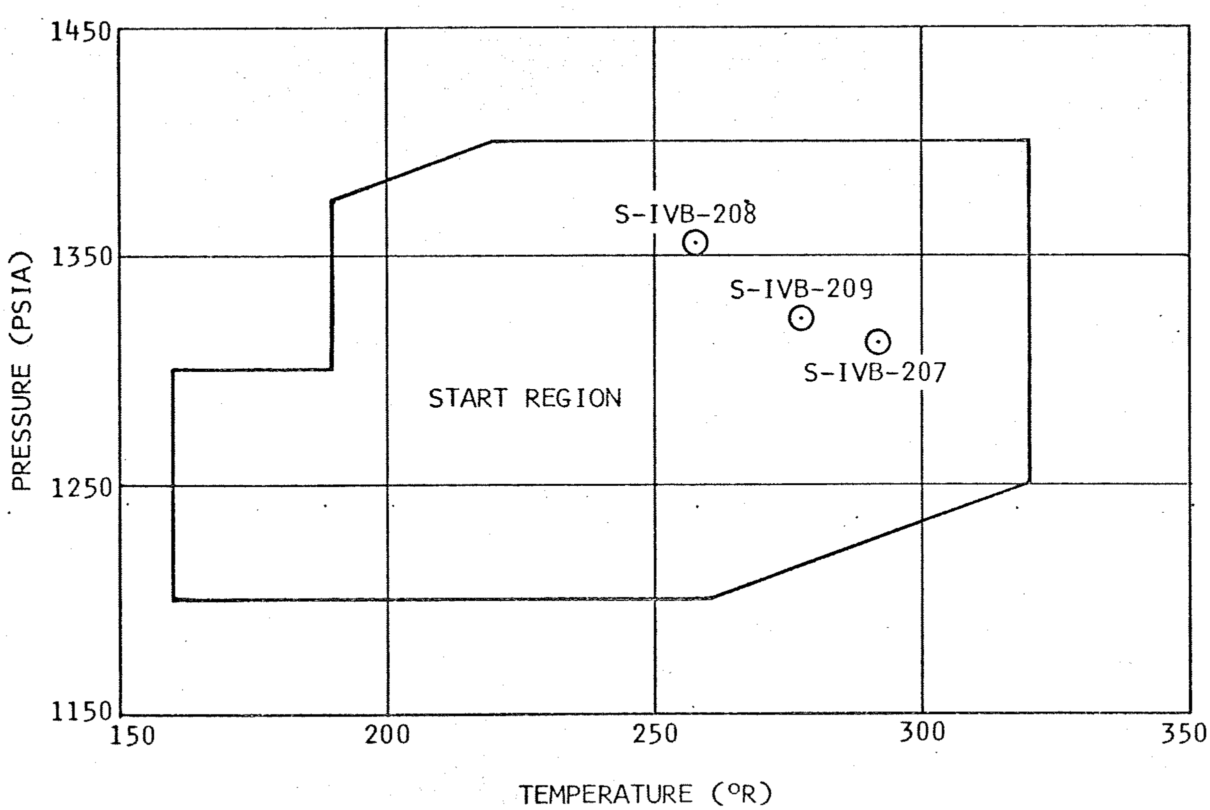

Figure 6-5. Engine Start Sphere Performance

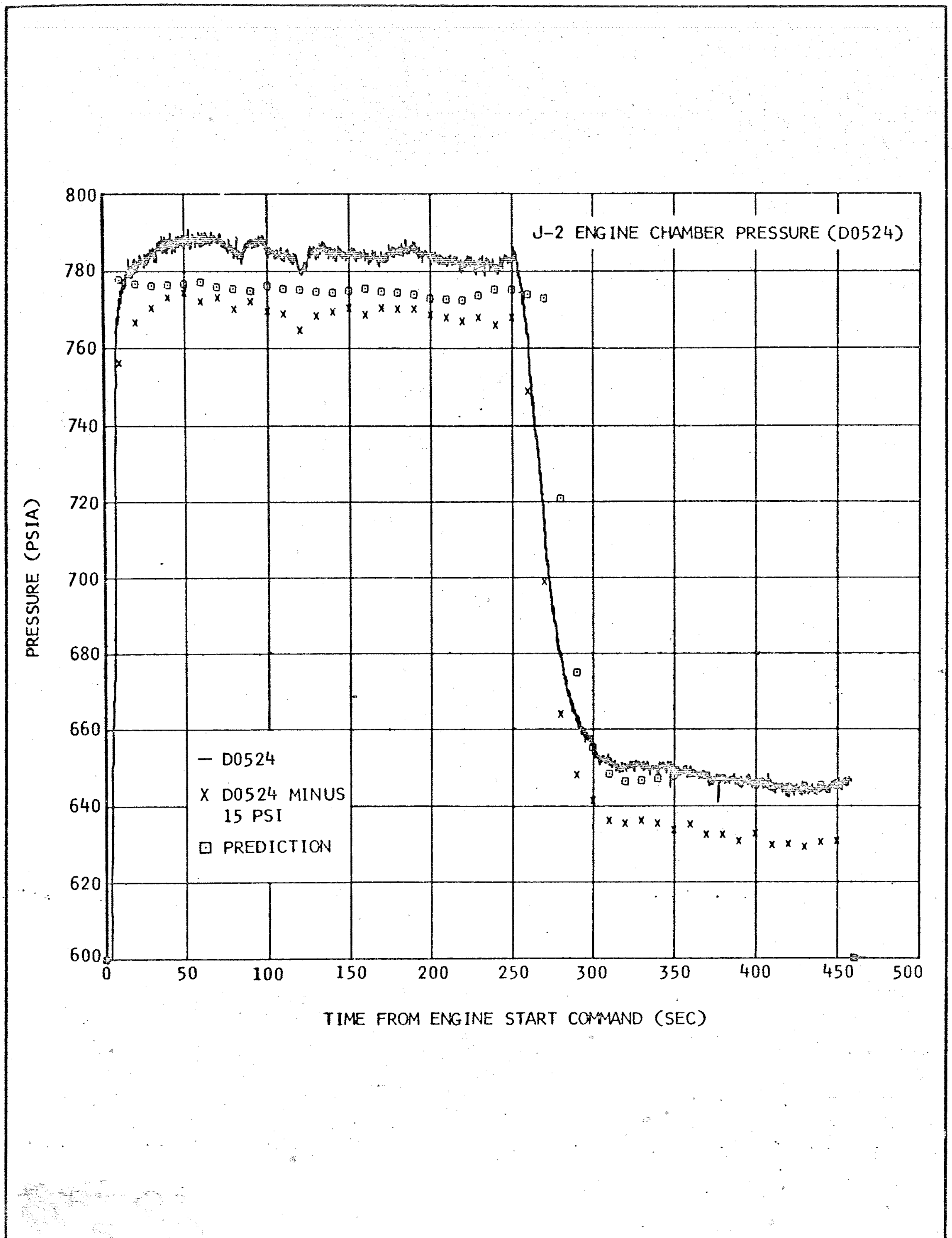

Figure 6-6. J-2 Engine Chamber Pressure

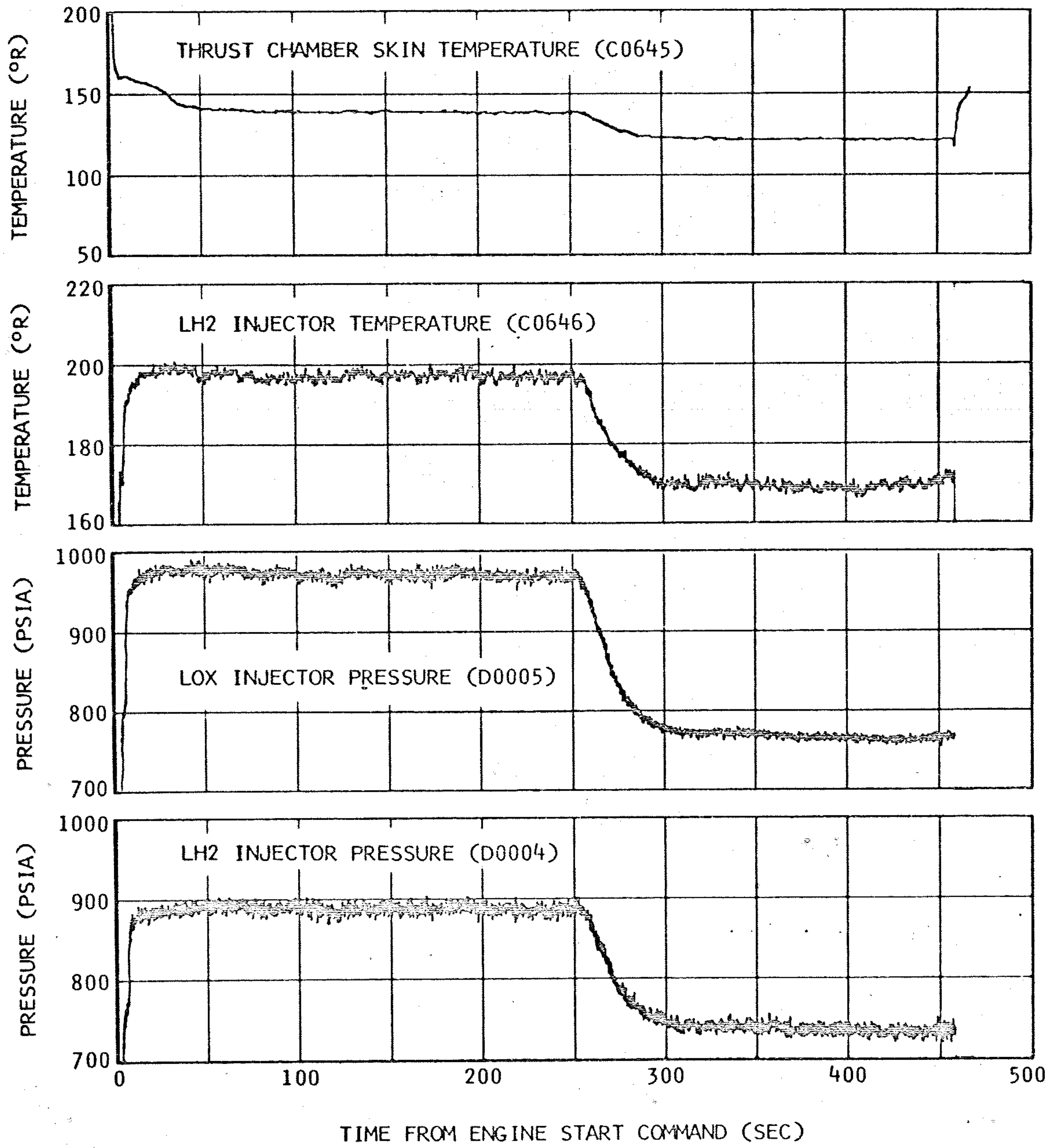

Figure 6-7. J-2 Engine Injector Supply Conditions

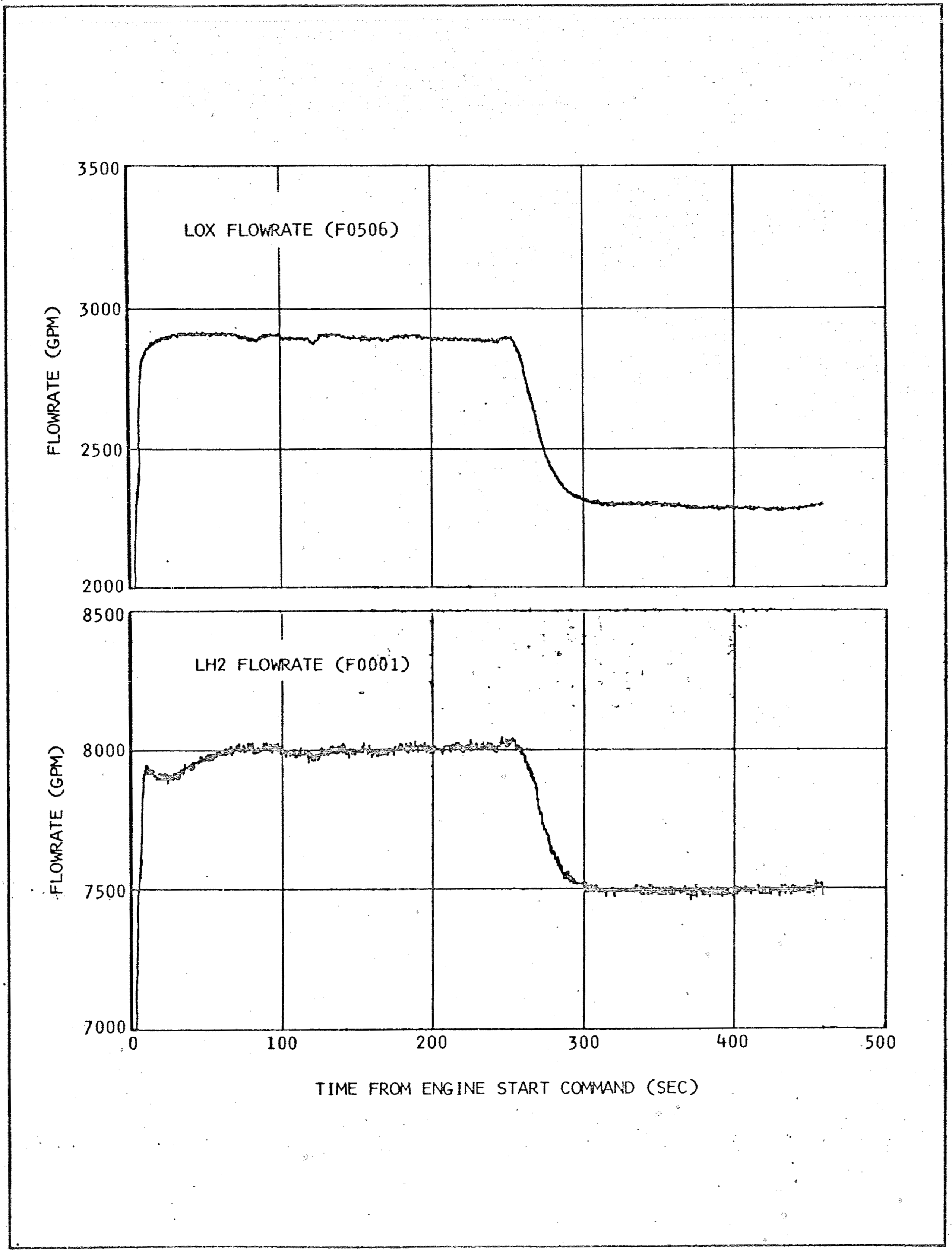

Figure 6-8. LOX and LH2 Flowrate

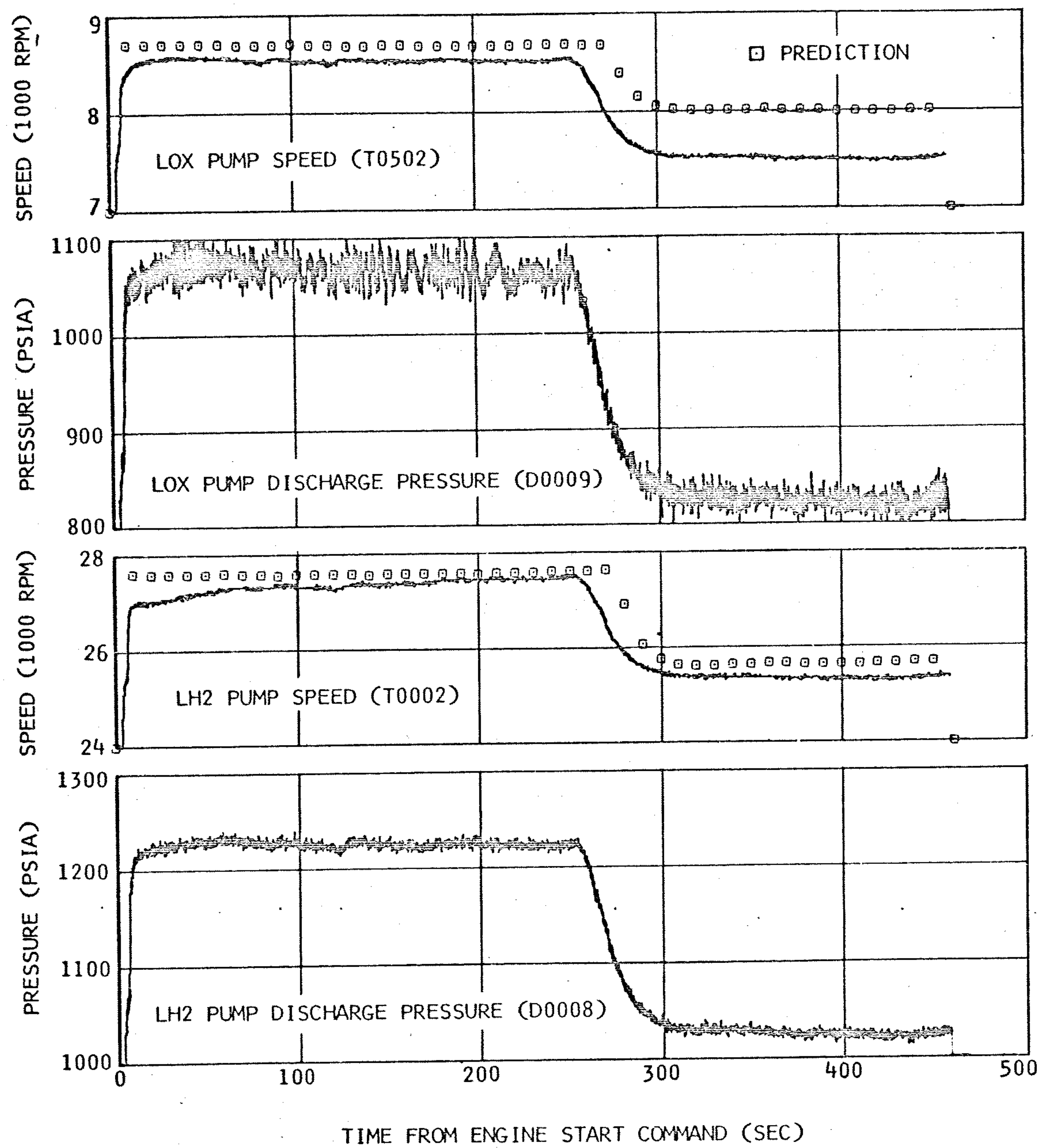

Figure 6-9. J-2 Engine Pump Operating Characteristics

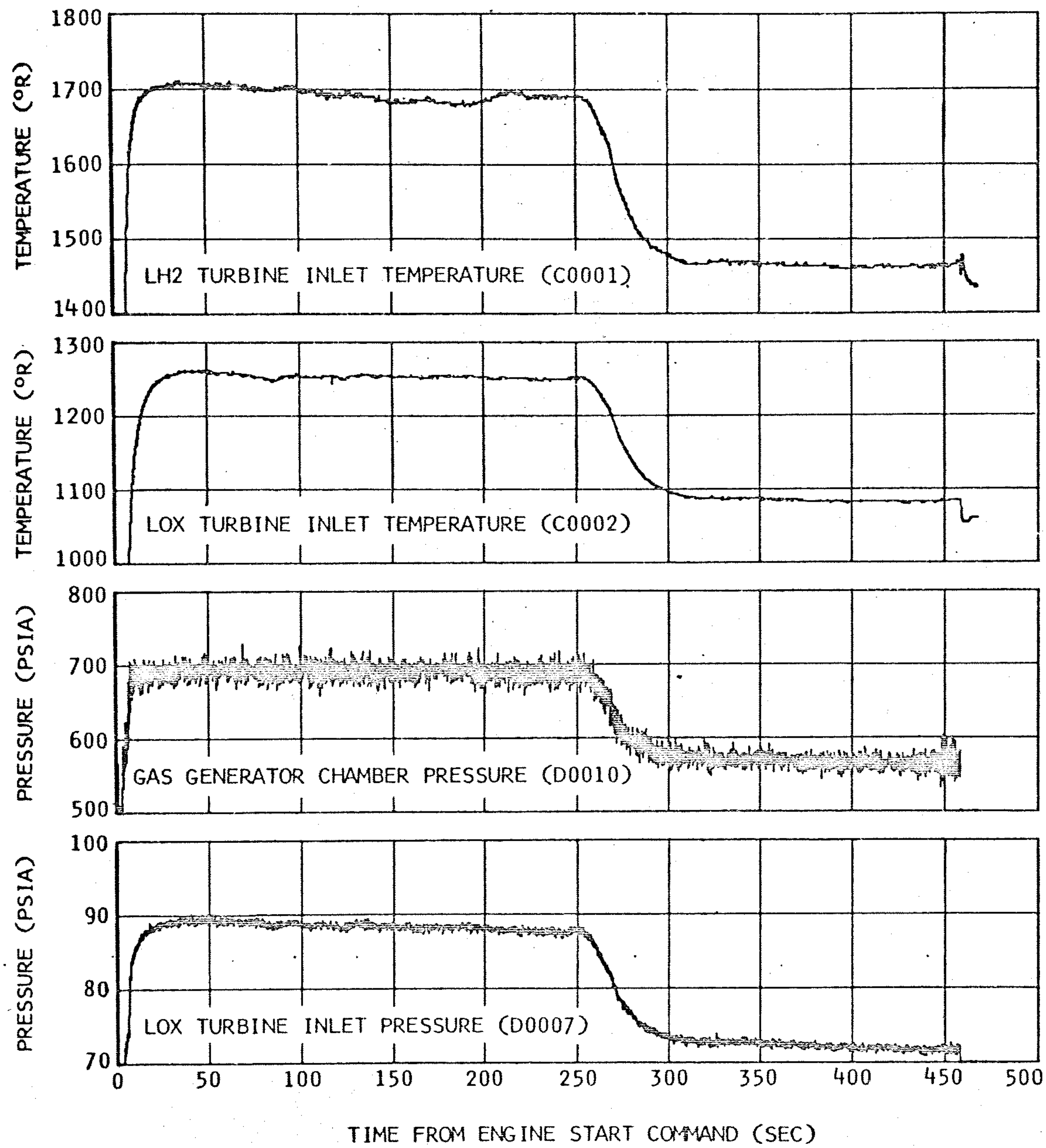

Figure 6-10. Turbine Inlet Operating Conditions

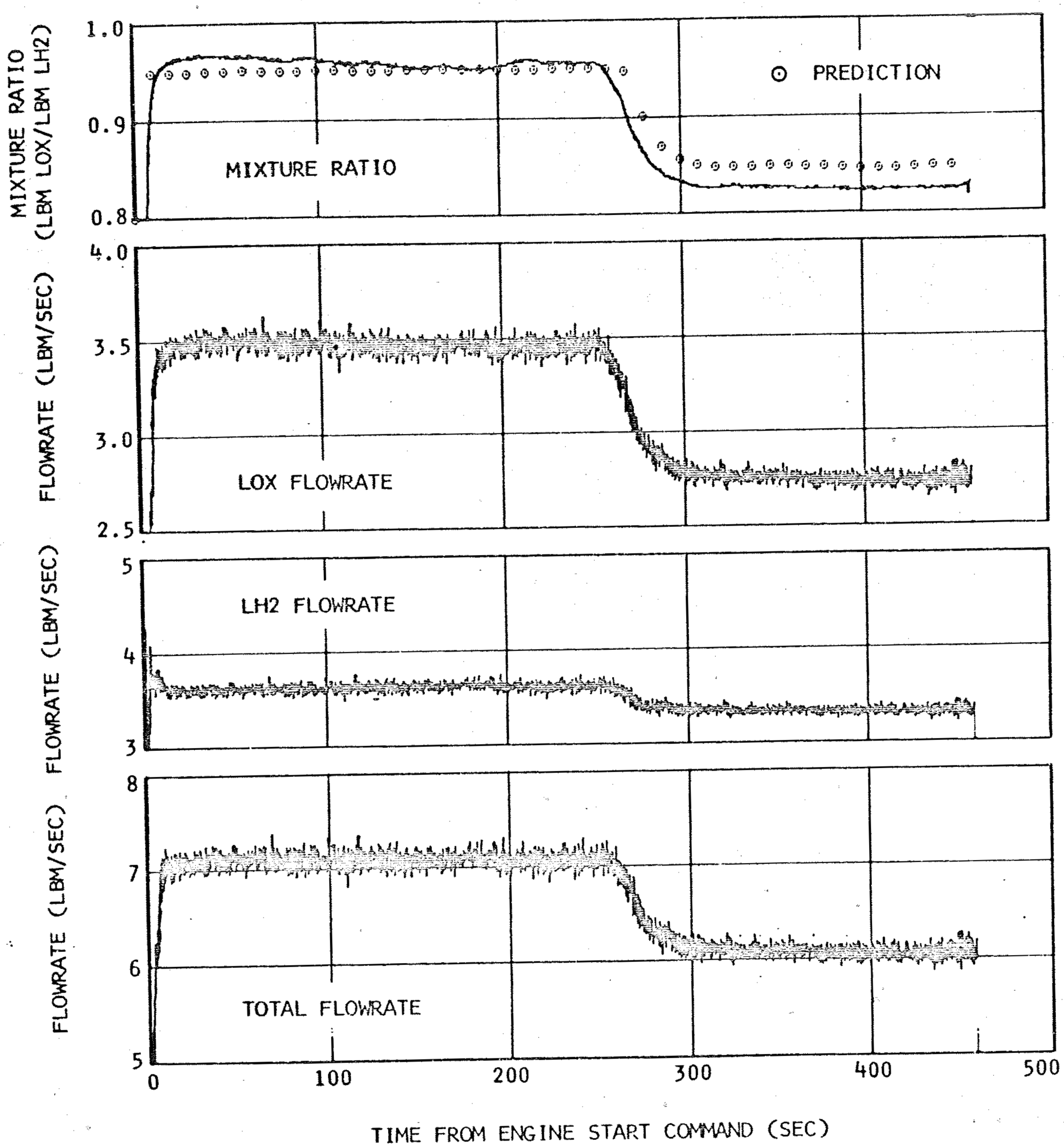

Figure 6-11. Gas Generator Performance

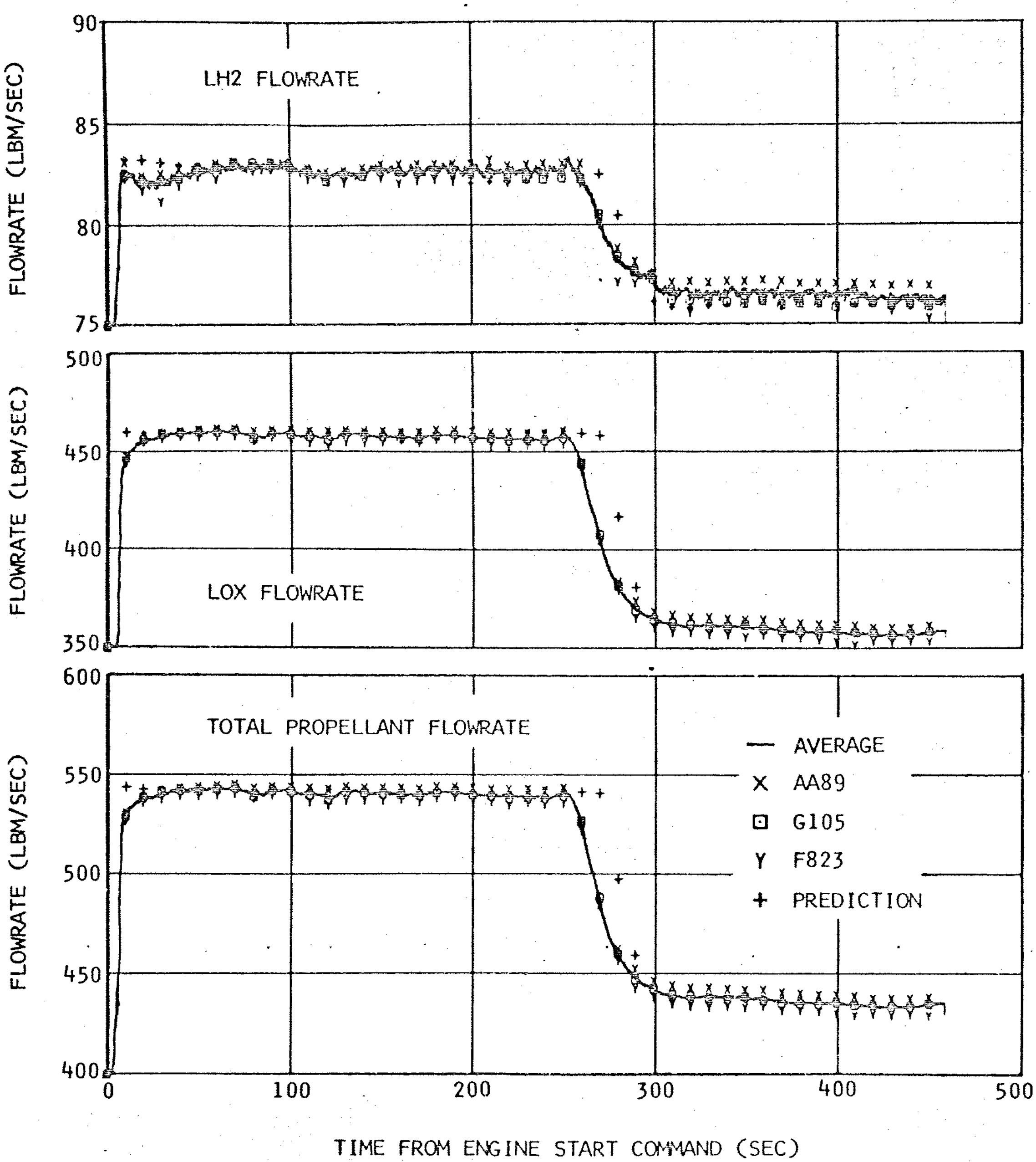

Figure 6-12. Engine Steady-State Performance (Sheet 1 of 3)

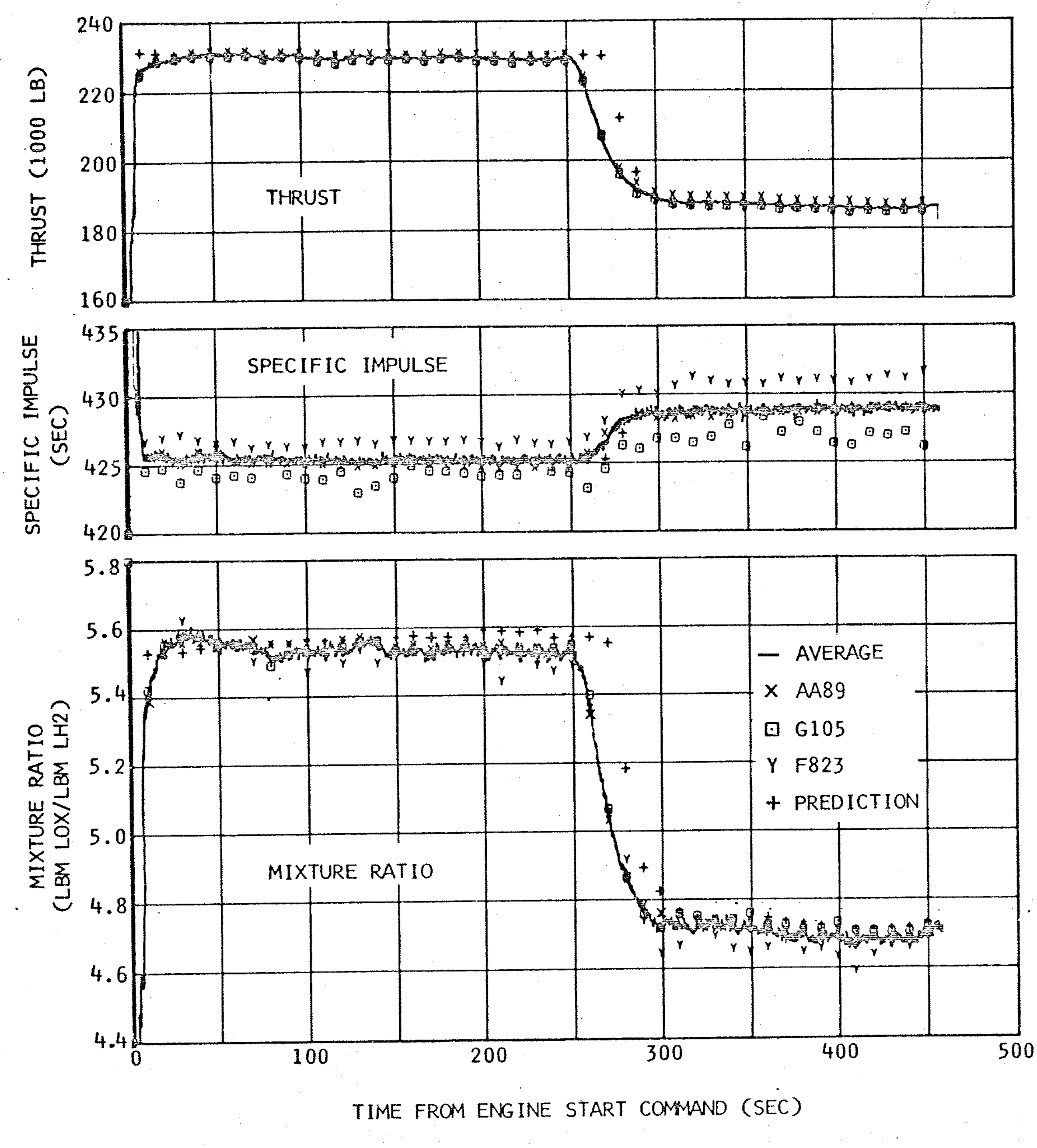

Figure 6-12. Engine Steady-State Performance (Sheet 2 of 3)

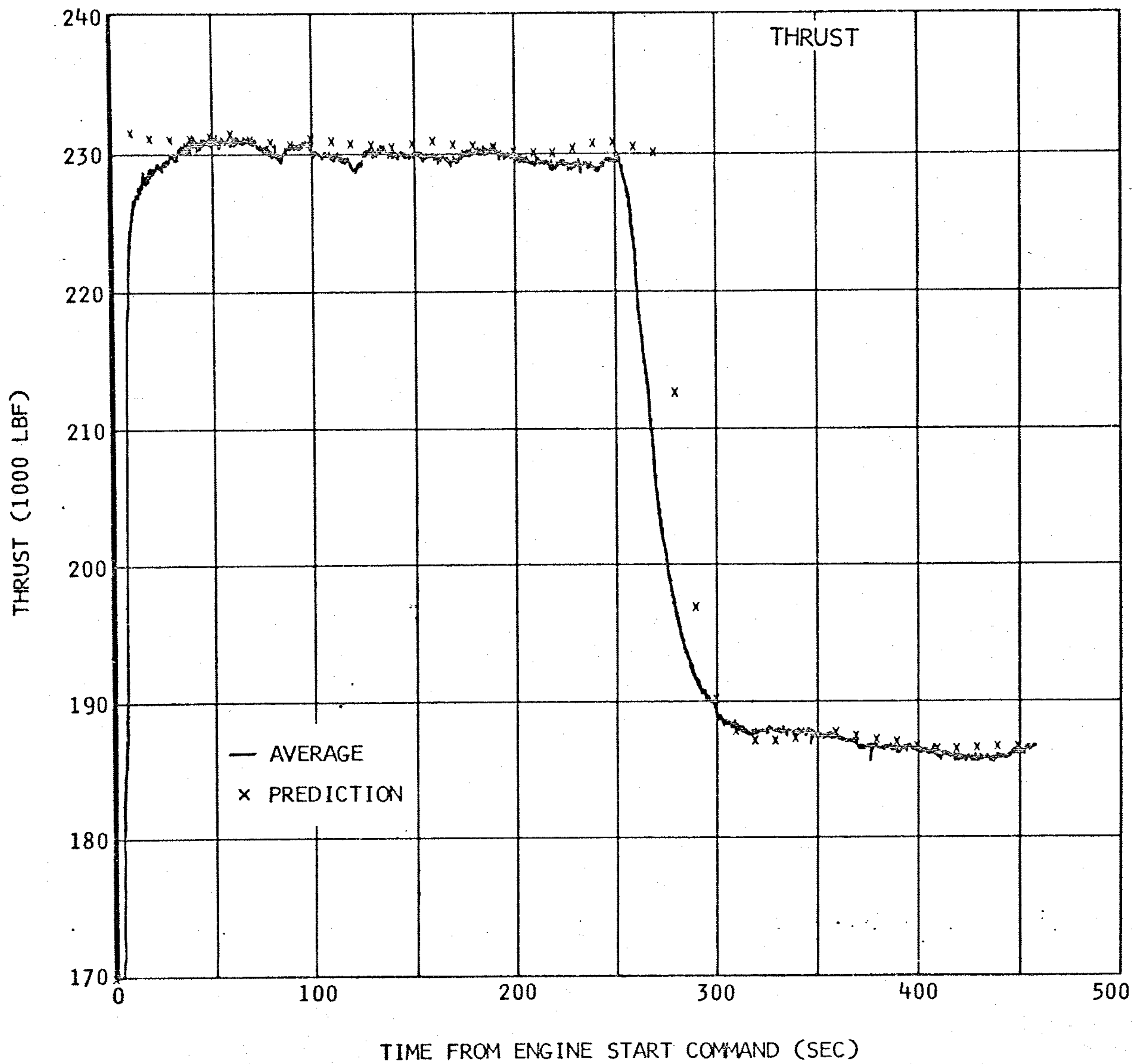

Figure 6-12. Engine Steady-State Performance (Sheet 3 of 3)

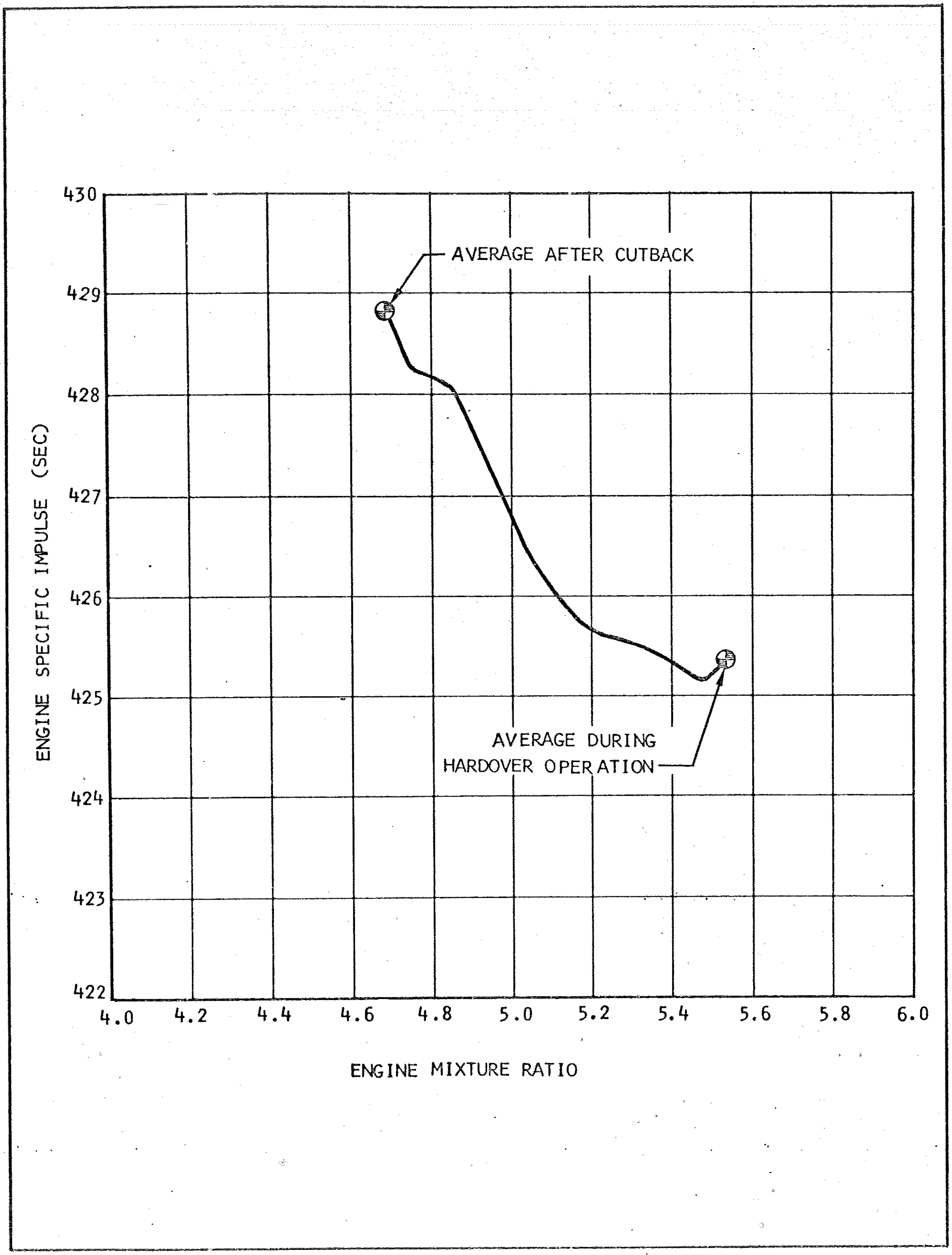

Figure 6-13. Specific Impulse versus Mixture Ratio

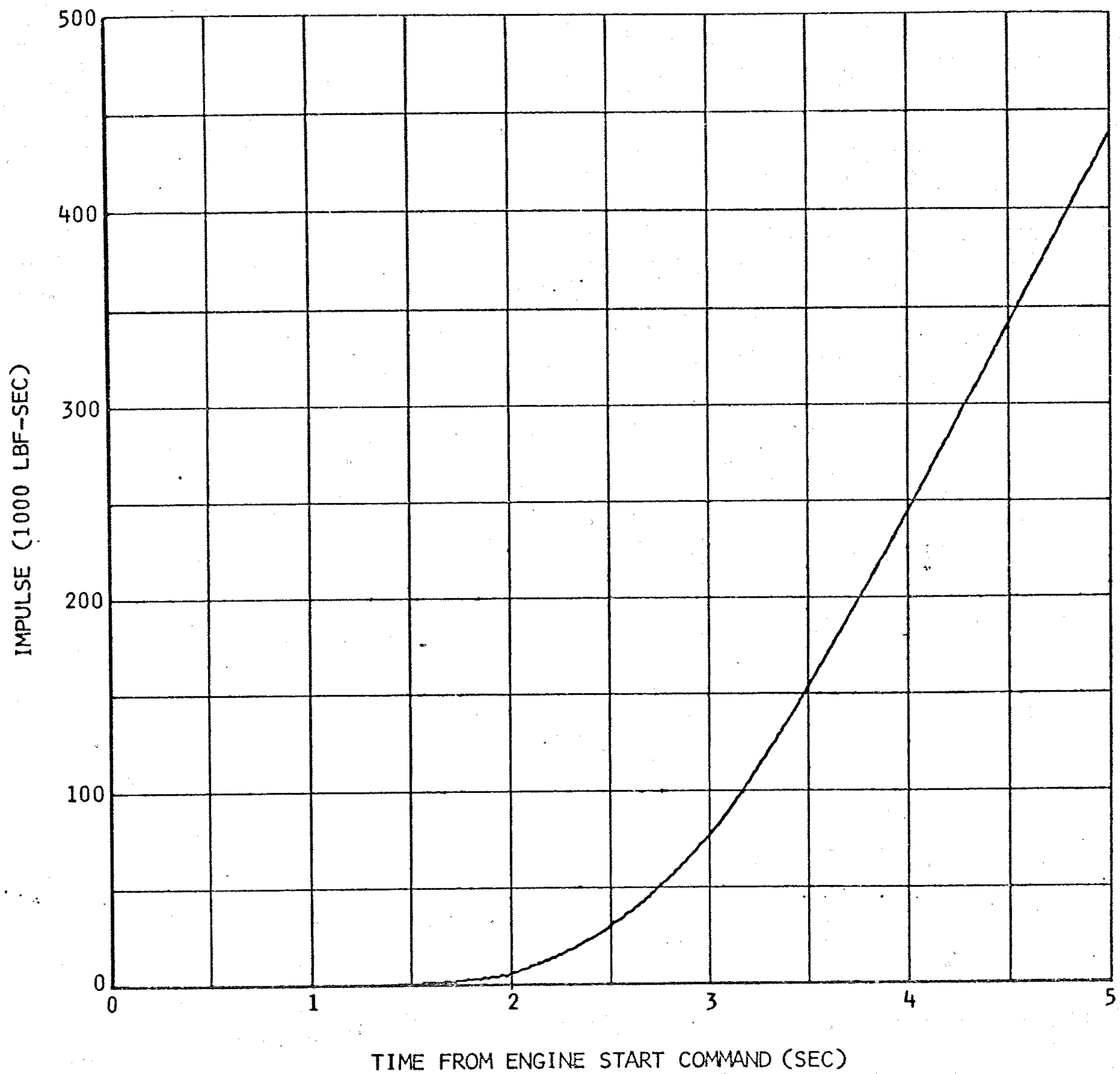

Figure 6-14. Total Accumulated Impulse After Engine Start Command

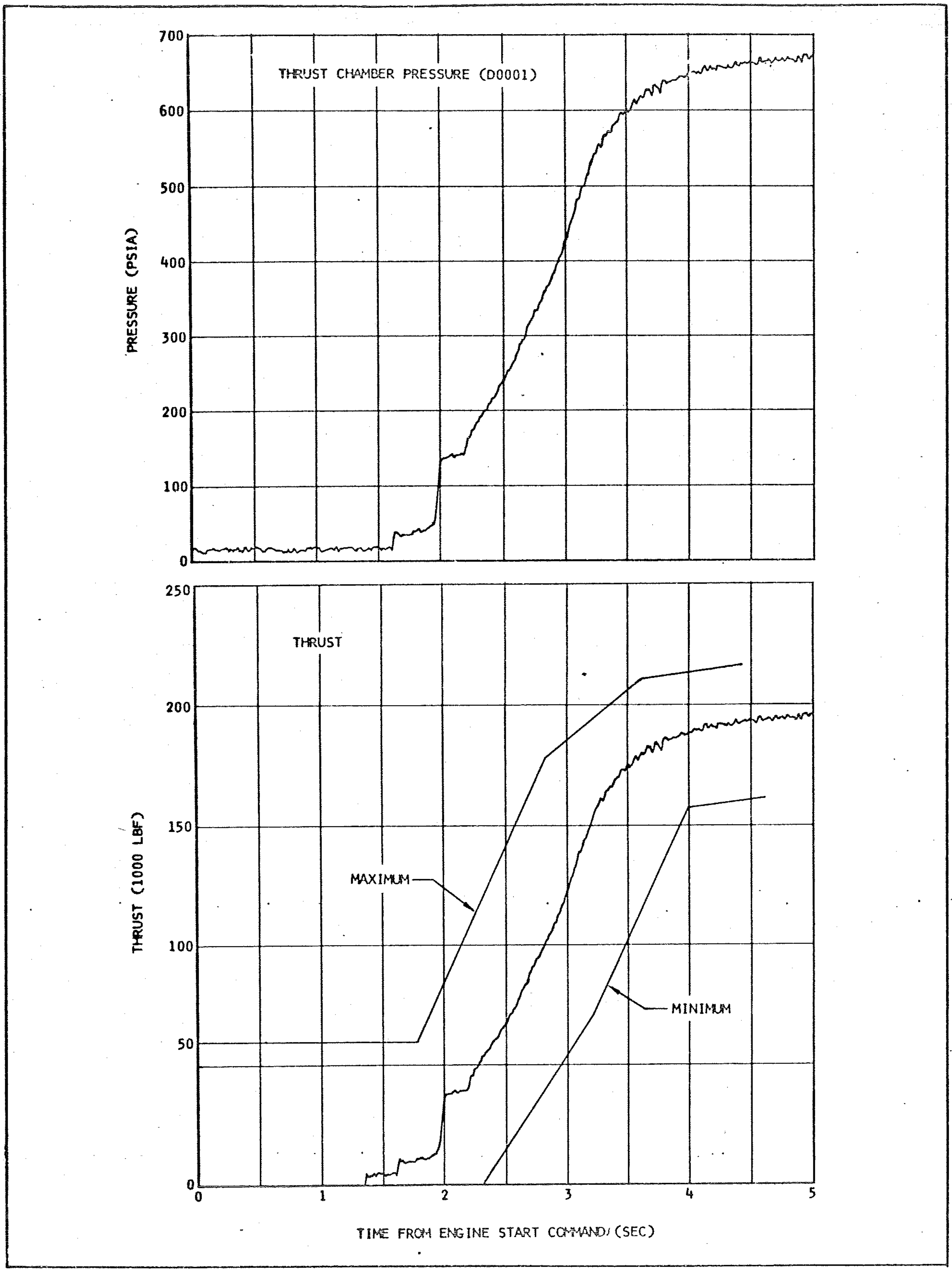

Figure 6-15. Engine Start Transient Characteristics

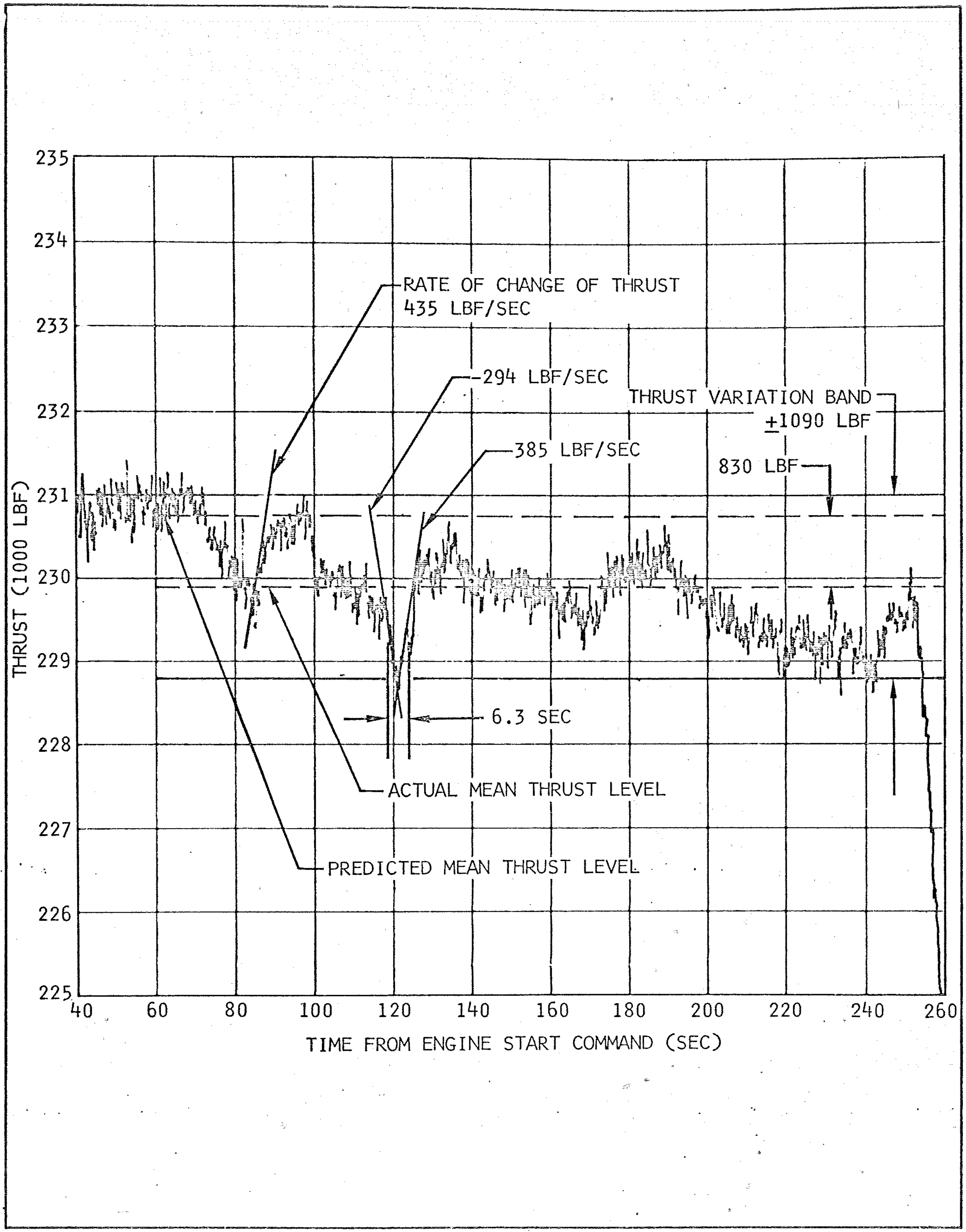

Figure 6-16. Thrust Variations (Sheet 1 of 3)

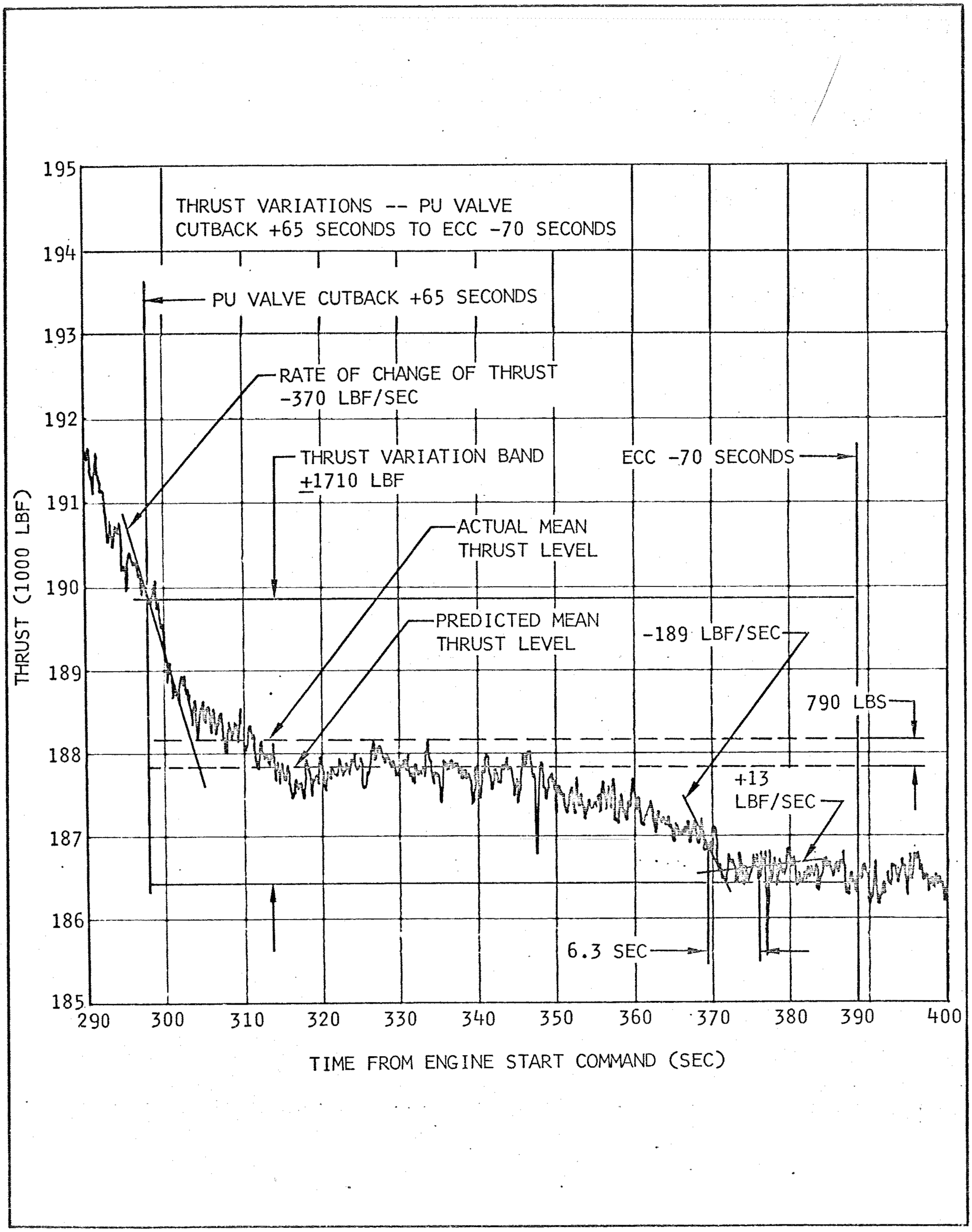

Figure 6-16. Thrust Variations (Sheet 2 of 3)

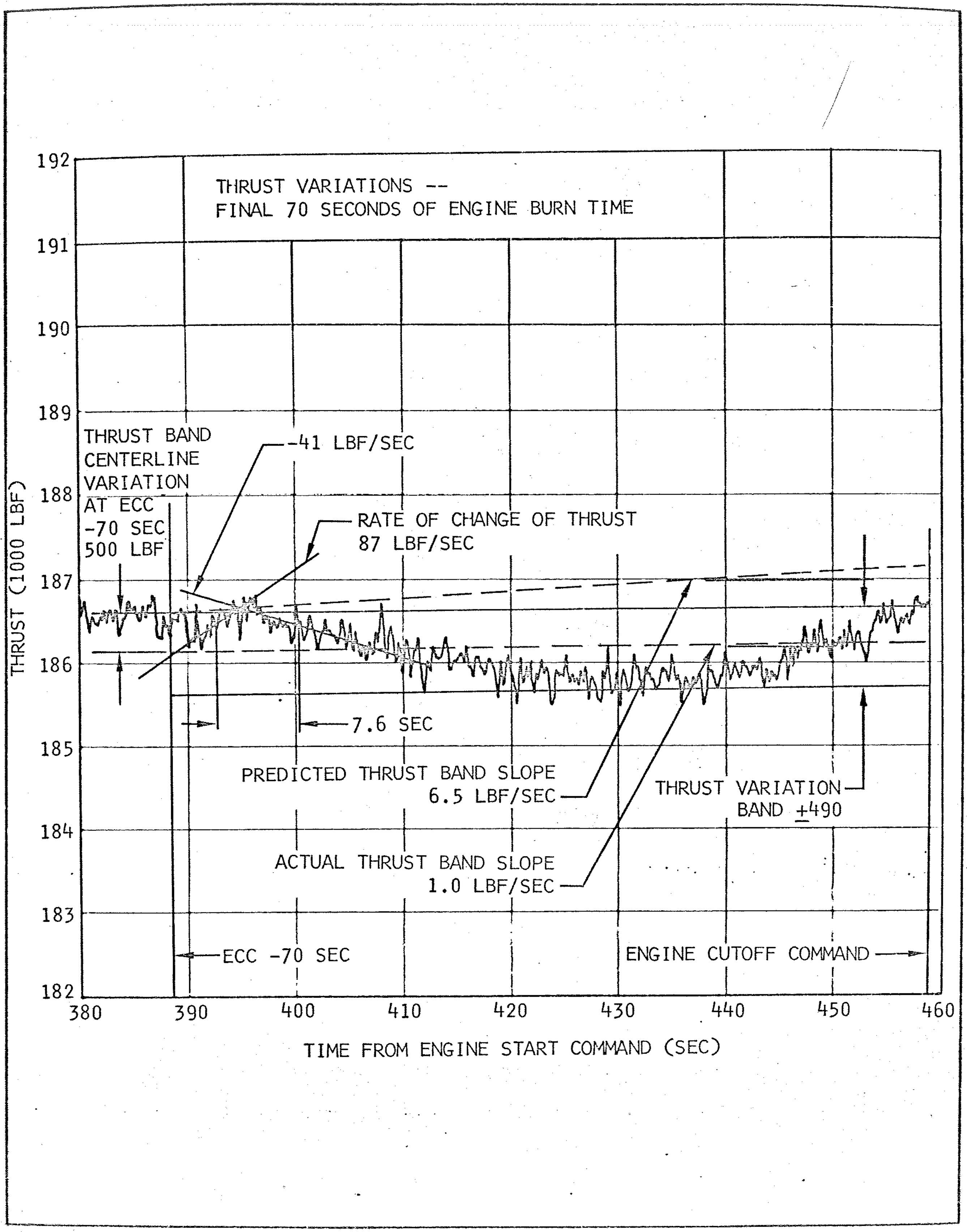

Figure 6-16. Thrust Variations (Sheet 3 of 3)

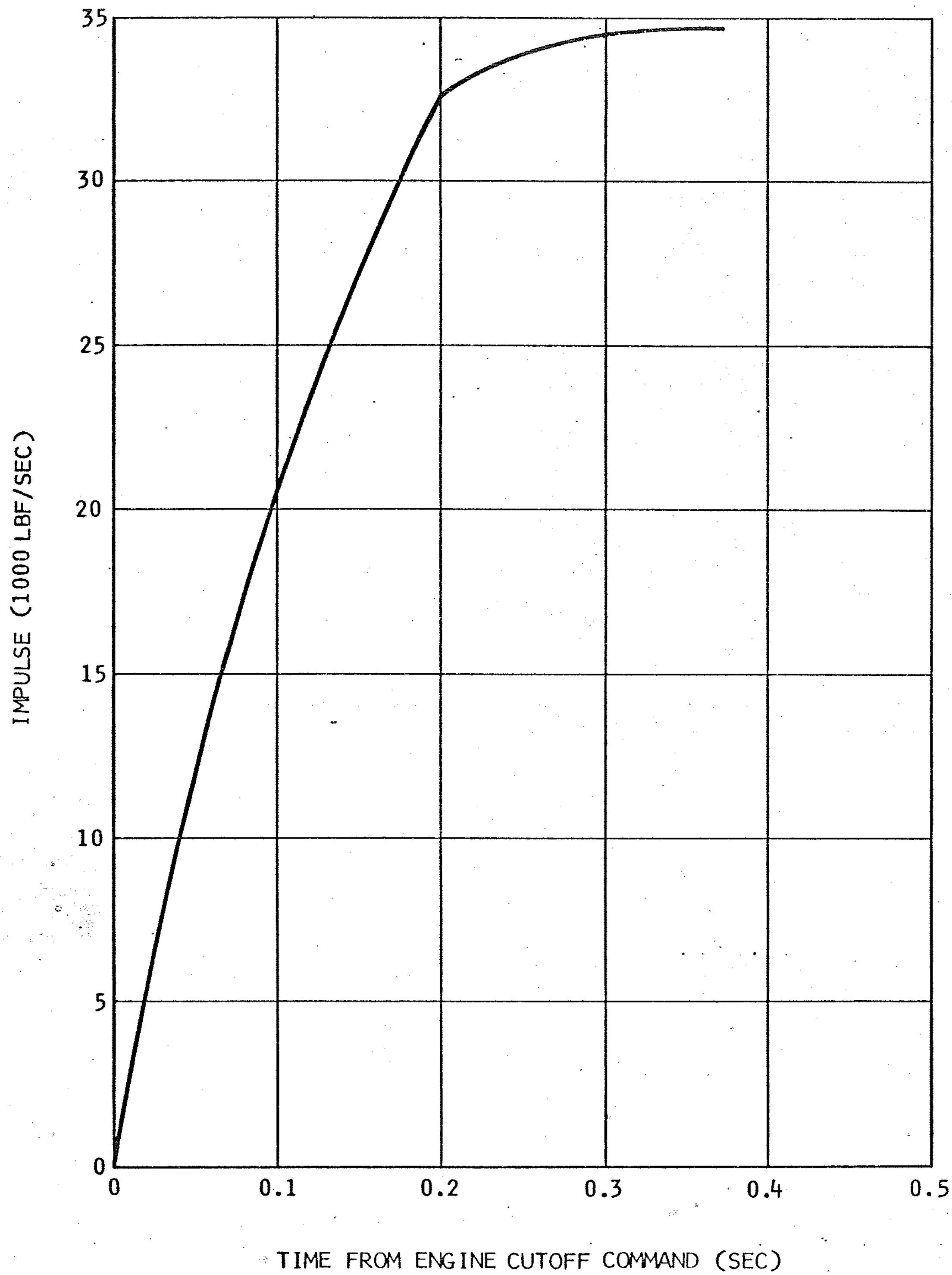

Figure 6-17. Total Accumulated Impulse After Engine Cutoff Command

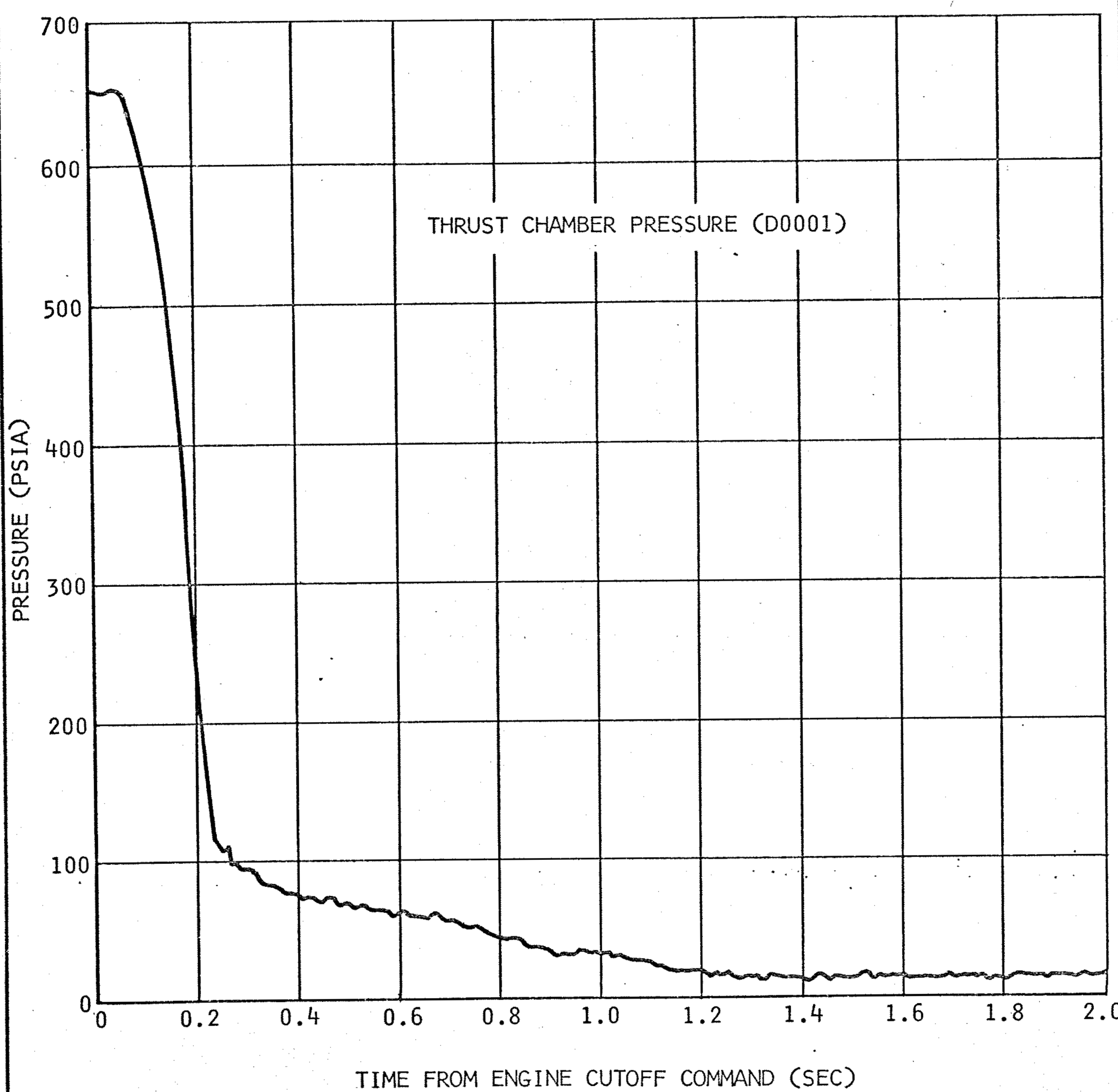

Figure 6-18. Engine Cutoff Transient Characteristics (Sheet 1 of 2)

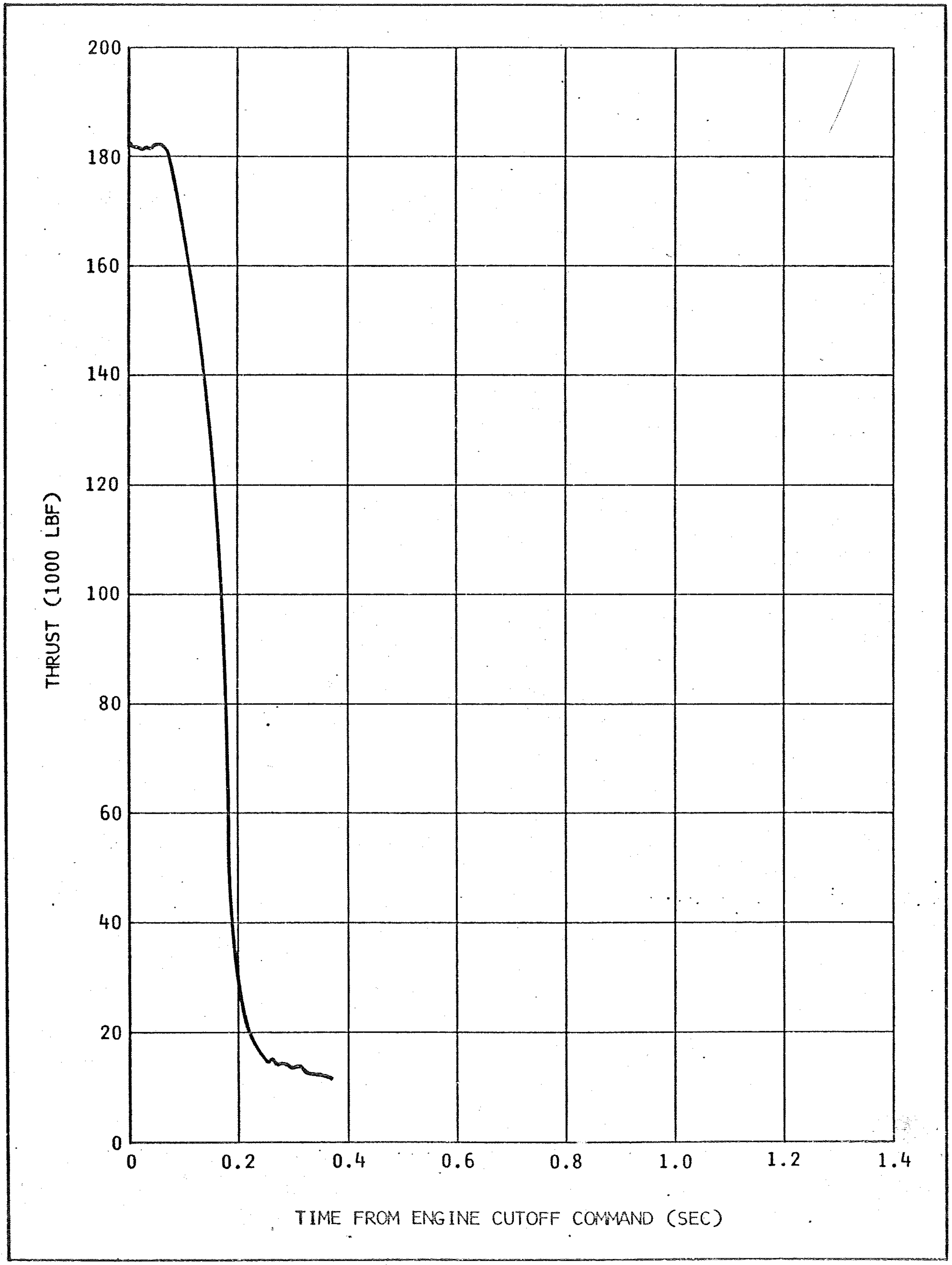

Figure 6-18. Engine Cutoff Transient Characteristics (Sheet 2 of 2)

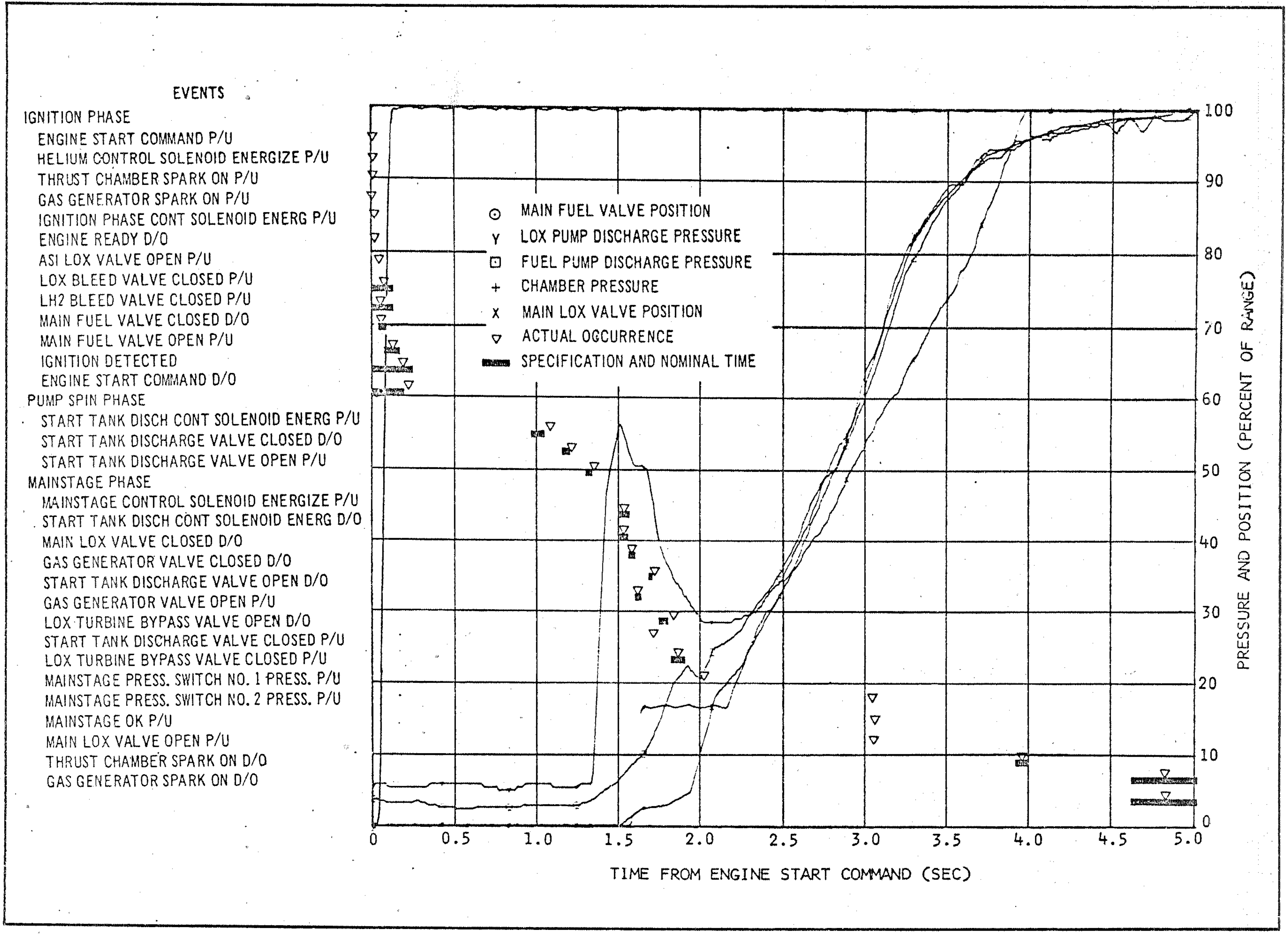

Figure 6-19. Engine Start Sequence

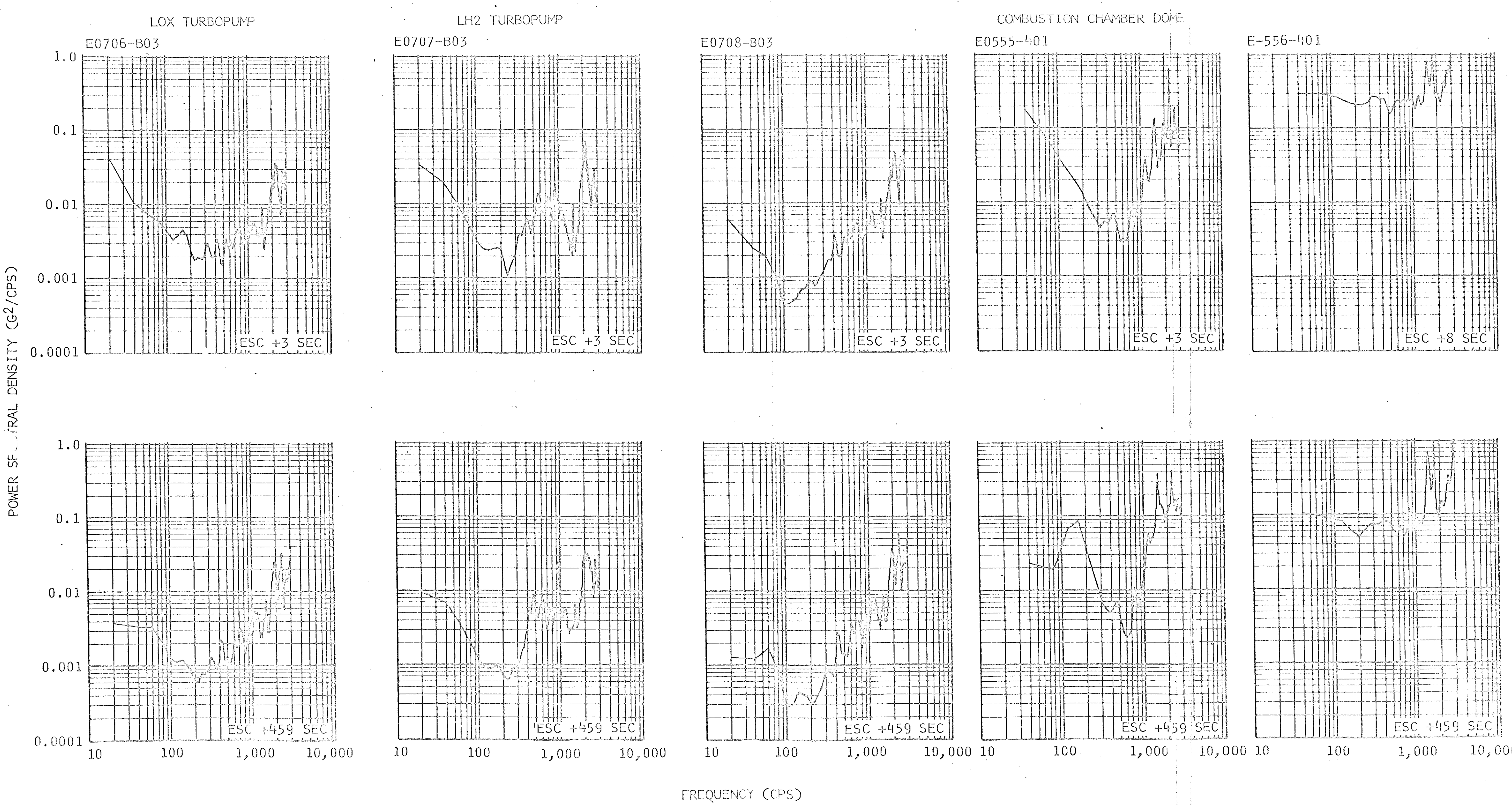

Figure 6-20. Engine Vibration

7

OXIDIZER SYSTEM

7. OXIDIZER SYSTEM

Due to a malfunction of the LOX tank pressurization control module, LOX NPSH fell below the minimum acceptable level for a 20-sec period shortly after Engine Start Command; however, there were no detrimental effects to the J-2 engine or to the remainder of the acceptance firing. With the exception of the above anomaly, the oxidizer system performance was acceptable.

7.1 Pressurization Control

The LOX tank pressurization system (figure 7-1) provided ullage pressure in the tank sufficient to satisfactorily complete the acceptance firing; however, a severe, though temporary, anomaly within the LOX tank pressurization control module caused the ullage pressure to drop to a low of 29.1 psia at ESC +27 sec. As a result, the engine pump NPSH dropped to 18.1 psi, 2.8 psi below the required minimum. The low ullage pressure also caused a common bulkhead negative differential pressure (refer to paragraph 15.4). In spite of these conditions, no detrimental effects were noted, the ullage pressure recovered, and the firing continued to a normal cutoff.

7.1.1 Prepressurization

The LOX tank prepressurization and pressure makeup cycles before simulated liftoff were accomplished from ground support equipment console "B" cold helium supply (figure 7-2). Helium purges of the vent valve and the LOX tank ullage pressure sensing line increased the ullage pressure to the vent relief setting twice, just prior to simulated liftoff and immediately after simulated liftoff. In order to protect the reusable ignition detection probe, the LOX tank was vented to 38.3 psia prior to Engine Start Command. Table 7-1 compares significant LOX tank prepressurization data from two previous acceptance firings.

7.1.2 Pressurization

The LOX tank pressurization system performance in maintaining the ullage pressure at the proper level was inadequate. During the start transient, the ullage pressure dropped to 29.1 psia (as compared to the predicted minimum of 34.8 psia) before recovering to a value within the normal band by ESC +60 sec; however, pressure after this time was as anticipated. As predicted, an overcontrol cycle was required five times to maintain the ullage pressure within the range of 39.6 to 37.6 psia during the firing.

Except for the period during the noted malfunction, the LOX tank pressurization system operation was nominal (figure 7-3) and compared well with that of the S-IVB-207 and 208 stage systems. Table 7-2 compares the S-IVB-209 stage pressurization system data with that from previous acceptance firings.

The cause of the dip in ullage pressure was an anomaly in the LOX tank pressurization control module during the initial chilldown of the system. The plenum discharge pressure (D0105) dropped to a low of 218 psia during this period as opposed to a nominal minimum of 300 psia. (Figure 7-4 presents a comparison of S-IVB-209 data with that from five previous stages for the first 100 sec of firing.) The pressure then recovered but remained below specification until the final overcontrol cycle started. At this time the regulator outlet pressure increased and stayed within the specification range until near cutoff, when the supply pressure caused it to fall below specification. The plenum discharge pressure has remained below specification levels through most of previous acceptance firings. This occurs because the regulator, which is flow-sensitive, is calibrated at a flowrate lower than that used during the acceptance firing. This will be corrected on subsequent stages.

The data indicated that the temporary drop in plenum pressure might have been caused by one of the following problems:

a. Leakage between the regulator and the plenum caused by differential contraction rates during chilldown.

b. Failure of the regulator to regulate properly during system chilldown.

c. Internal blockage in the system between the regulator and the plenum.

The possibility of leakage was discounted after initial calculation showed that a leakage rate in the order of 600 scfm would have been required. This rate is entirely too high to be reasonable.

After the firing, the module was removed from the stage, inspected, and tested. The testing indicated that the regulator would function normally when thoroughly chilled but tended to regulate to low plenum pressures while being chilled. The low plenum pressure during childown is presumed to be due to choking in the regulator metering system, causing the regulator poppet to respond to metering system anomalies rather than the pressures downstream of the poppet; however, even though there is a strong indication that this explains the low plenum pressure, this is not the total explanation of the problem.

When the module was inspected, the No. 1 shutoff valve, the shutoff pilot seat, the module outlet filter, and some parts in the regulator dome were rusted, indicating that moisture had been present in the system. Also, three of the separators in the regulator were fractured. The exact point in time when the moisture was introduced into the regulator has not been determined. If the moisture had been present during the acceptance firing, there could have been an added pressure drop due to moisture freezing on the outlet filter.

At the present time the anomaly of the pressurization module seems to have a double cause: the regulator thermal choking and the moisture collecting on the outlet filter. Additional testing is presently being conducted to substantiate these presumptions.

7.2 Cold Helium Supply

At Engine Start Command, the six cold helium spheres contained a total of 246 lbm of helium at 3,043 psia and 42.25 deg R. The conditions of the cold helium spheres at significant times are presented in table 7-2. The temperature and pressure profiles were normal and are shown in figure 7-5.

7.3 J-2 Heat Exchanger

The J-2 heat exchanger functioned satisfactorily and compared well with previous tests (figure 7-6). A comparison of significant S-IVB-209 stage heat exchanger data with that from two previous acceptance firings is presented in table 7-3.

7.4 LOX Pump Childown

The LOX pump chilldown system performed adequately. At Engine Start Command, the NPSH at the LOX pump inlet was above the minimum required at that time. The chilldown system data and the results of the performance calculations are presented in figures 7-7 and 7-8 and compared with previous test data in table 7-4.

The chilldown pump was started 598 sec prior to simulated liftoff in an attempt to simulate the KSC launch countdown sequence. Subsequent to the establishment of this sequence, it was determined that, at KSC, chilldown starts at approximately liftoff minus 300 sec. This sequence will be reflected in future STC testing. The chilldown shutoff valve was left open until T_0 +602.8 sec (approximately ECC -10 sec), also in simulation of the flight sequence.

The heat input rates for the three sections of the chilldown system were computed using flowrate and temperature data. The three sections are defined as follows:

a. Tank to turbopump inlet
b. Pump inlet to bleed valve
c. Bleed valve to tank inlet.

These heat input rates decreased rapidly as heat was removed from the hardware during the first minute of chilldown, then remained relatively constant during the subsequent chilldown process (figure 7-8). During steady-state pressurized chilldown, the heat input rates were within the range of those obtained for previous acceptance firings (table 7-4).

The chilldown pump flowrate and differential pressure at 46.5 gpm and 11.5 psid were both somewhat higher than they were on previous firings. This higher flowrate and consequently increased differential pressure is attributed to a change in LOX chilldown pump design. This stage is the first to utilize a pump with an improved inducer. The high level of differential pressure measured by D0219, however, is not supported by the remainder of the system data; it appears to be approximately 20 percent high. This discrepancy has been noted during previous firings;

however, no definite explanation is presently available. The subject is under investigation.

7.5 Engine LOX Supply

The LOX supply system (figure 7-9) delivered the necessary quantity of LOX to the engine pump inlet throughout the engine firing and maintained the pressure and temperature conditions within the specified range except for a 20-sec period after engine start. During this time, NPSH decreased to 18.1 psi, as opposed to the required 20.9 psi; however, no detrimental effects were attributed to this occurrence.

The cause of the problem originated in the LOX tank pressurization system and is discussed in paragraph 7.1.2. The data and calculated performance are presented in figure 7-10. Table 7-5 compares S-IVB-209 stage data and calculated performance with that from two previous acceptance firings.

The LOX pump inlet pressure and temperature were plotted in the engine LOX pump operating region (figure 7-11) and showed that the engine LOX pump inlet conditions were met satisfactorily during most of the engine operation. In figure 7-12, the pump inlet temperature is plotted against the mass remaining in the LOX tank during engine operation and is compared to the S-IVB-208 and 503N acceptance firing data. These data have been biased to an identical initial condition to correct for instrumentation error, different heating rates during prepressurization, and other test-to-test variations. It is apparent that the heat transfer to the LOX was very similar to that noted on previous stages.

7.6 LOX Tank Vent and Relief Valve Performance

The LOX tank vent and relief valve was tested during CD 614084. The valves relieved at 43.6, 43.5, and 43.4 psia; however, when the tank was allowed to self-pressurize, ullage pressure stabilized at 42.0 psia and, after several minutes at this level, the vent valve talkback was received. In addition, the valve relieved twice at 42.1 psia, following prepressurization. The different pressure ranges are attributable to the rate of ullage pressure rise; auxiliary ground pressurization with a very rapid pressure rise rate is used during the vent and relief valve test versus the slow rise caused by self-pressurization.

TABLE 7-1
LOX TANK PREPRESSURIZATION DATA

PARAMETER	S-IVB-207	S-IVB-208	S-IVB-209
Prepressurization duration (sec)	16	19	17.1
Number of makeup cycles	1	2	2
Prepressurization flowrate (lbm/sec)	0.22 to 0.32	0.22 to 0.30	0.22 to 0.29
Helium added to LOX tank			
During main prepressurization (lbm)	4.00	3.87	3.4
During makeup cycles (lbm)	0.66	0.65	0.63
Ullage pressure			
At prepressurization initiation (psia)	15.2	15.0	15.0
At prepressurization termination (psia)	40.5	39.2	39.9
At Engine Start Command (psia)	41.9	41.4	38.3
Events (sec from ESC)			
Prepressurization initiation	-311	-315	-312.5
Prepressurization termination	-295	-296	-295.4

TABLE 7-2 (Sheet 1 of 2)
LOX TANK PRESSURIZATION DATA

PARAMETER	S-IVB-207	S-IVB-208	S-IVB-209
Number of secondary flow intervals	7	6	5
Control pressure switch range (psia)	37.43 to 39.45	37.5 to 39.5	37.6 to 39.6
Ullage pressure			
At Engine Start Command (psia)	41.9	41.4	38.3
Minumum during start transient (psia)	36.3	34.25	29.1
LOX tank pressurization total flowrate			
During overcontrol (lbm/sec)	0.35 to 0.47	0.36 to 0.44	0.39 to 0.47
Predicted (lbm/sec)	0.42 to 0.46	0.39 to 0.47	0.41 to 0.45
During undercontrol (lbm/sec)	0.265 to 0.34	0.26 to 0.32	0.28 to 0.37
Predicted (lbm/sec)	0.29 to 0.33	0.27 to 0.32	0.29 to 0.32
Cold helium sphere conditions			
Mass in spheres at engine start (lbm)	254	254	246.4
Pressure at engine start (psia)	2,990	3,046	3,043
Average temperature at engine start (deg R)	39.7	40.0	42.2
Mass in spheres at engine cutoff (lbm)	97	100	82.5
Helium consumed during firing as calculated from sphere conditions (lbm)	157	154	163.9

TABLE 7-2 (Sheet 2 of 2)
LOX TANK PRESSURIZATION DATA

PARAMETER	S-IVB-207	S-IVB-208	S-IVB-209
Cold helium sphere conditions (Continued)			
Helium consumption calculated by integration of flowrate (lbm)	155	142	154
Pressure at engine cutoff (psia)	640	648	550
Average temperature at engine cutoff (deg R)	44.8	42.2	43.0
Estimated temperature loss in 10 feet of insulated line			
During overcontrol (deg R)	7	11	9
During undercontrol (deg R)	17	28	23
Maximum LOX tank vent inlet temperature (deg R)	496	506	500

TABLE 7-3
J-2 HEAT EXCHANGER DATA

PARAMETER	S-IVB-207	S-IVB-208	S-IVB-209
Flowrate through heat exchanger			
During overcontrol (lbm/sec)	0.215	0.20	0.20 to 0.215
During undercontrol (lbm/sec)	0.085	0.080	0.085
Heat exchanger inlet temperature			
During overcontrol (deg R)	60	60	55
During undercontrol (deg R)	73	70	68
Heat exchanger outlet temperature*			
During overcontrol (deg R)	957	980	959
During undercontrol (deg R)	1,002	1,000	1,006
Heat exchanger outlet pressure			
During overcontrol (psia)	335 to 360	315 to 345	325 to 350
During undercontrol (psia)	385 to 407	380 to 400	355 to 410
Heat exchanger outlet temperature at Engine Cutoff Command (deg R)	902	906	898
Average LOX vent inlet pressure			
During overcontrol (psia)	72	69	70
During undercontrol (psia)	51	51	50

*Estimated from measurement C0009 and uninsulated line temperature loss.

TABLE 7-4 (Sheet 1 of 2)
LOX CHILLDOWN SYSTEM PERFORMANCE

PARAMETER	S-IVB-207	S-IVB-208	S-IVB-209
NPSH (psi)			
At Engine Start Command	33.2	32.0	29.7
Minimum required at engine start (psi)	16.5	16.5	16.5
Average flow coefficient (sec^2/in^2ft^3)	15.3	15.6	15.0
Pump inlet conditions at engine start			
Pressure (psia)	50.0	49.5	46.3
Temperature (deg R)	164.6	165.6	164.4
Heat absorption rate (Btu/hr)			
Section 1 (tank to turbopump inlet)	2,000	4,000	3,000
Section 2 (pump inlet to bleed valve)	14,200	14,000	17,100
Section 3 (bleed valve to tank inlet)	2,800	2,000	4,300
Total	19,000	20,000	24,400
Chilldown flowrate (gpm)			
Unpressurized	36.7	37.7	40.6
Pressurized	41.0	43.0	46.5
Pressure drop (psi)			
Unpressurized	8.7	8.0	9.0
Pressurized	10.0	10.0	11.5
Events (sec from T_0)			
Chilldown start	-302	-602	-598.2
Prevalve Open Command	146.88	146.39	147.56

TABLE 7-4 (Sheet 2 of 2)
LOX CHILLDOWN SYSTEM PERFORMANCE

PARAMETER	S-IVB-207	S-IVB-208	S-IVB-209
Events (sec from T_0) (Continued)			
Prevalve closed signal dropout	147.50	147.16	149.03
Prevalve open signal pickup	149.08	148.69	150.57
Delay between prevalve open signal and pickup of signal	2.26	2.30	3.01
Chilldown shutoff valve closed	150	566.57	602.8
Prepressurization	-161	-165	-160.7
Engine Start Command	150.86	150.27	151.847
Engine Cutoff Command	598.94	576.87	610.682

TABLE 7-5
LOX PUMP INLET CONDITIONS

PARAMETER	S-IVB-207	S-IVB-208	S-IVB-209
Pump inlet conditions at engine start			
Static pressure (psia)	50.0	49.5	46.3
Temperature (deg R)	165.2	165.6	164.4
NPSH requirements			
At high EMR (psi)	21.0	20.2	20.9
After EMR cutback (psi)	14.9	14.25	15.8
NPSH available			
At Engine Start Command (psi)	33.2	32.0	29.7
Minimum during start transient (psi)	26.0	22.8	18.1
Time of occurrence (sec from ESC)	20	21	27
At Engine Cutoff Command (psi)	21.8	20.7	23.7
Minimum during firing (psi)	21.8	20.7	18.1
Time of occurrence (sec from ESC)	ECC	ECC	27
Feed duct during high EMR			
Pressure drop (psi)	1.4	1.8	2.3
Flowrate (lbm/sec)	450	468	457
Feed duct after EMR cutback			
Pressure drop (psi)	0.4	1.3	1.3
Flowrate (lbm/sec)	368	379	359

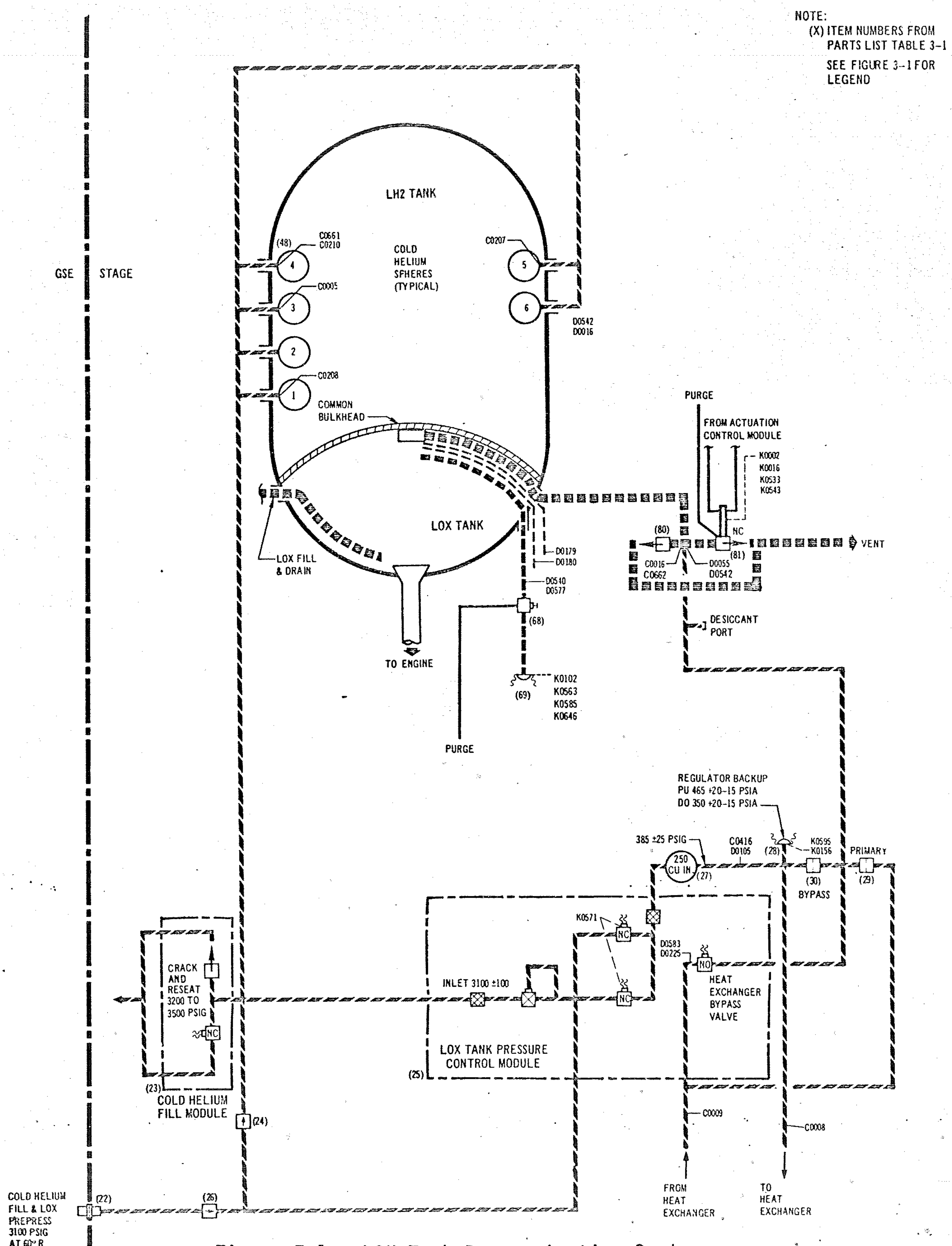

Figure 7-1. LOX Tank Pressurization System

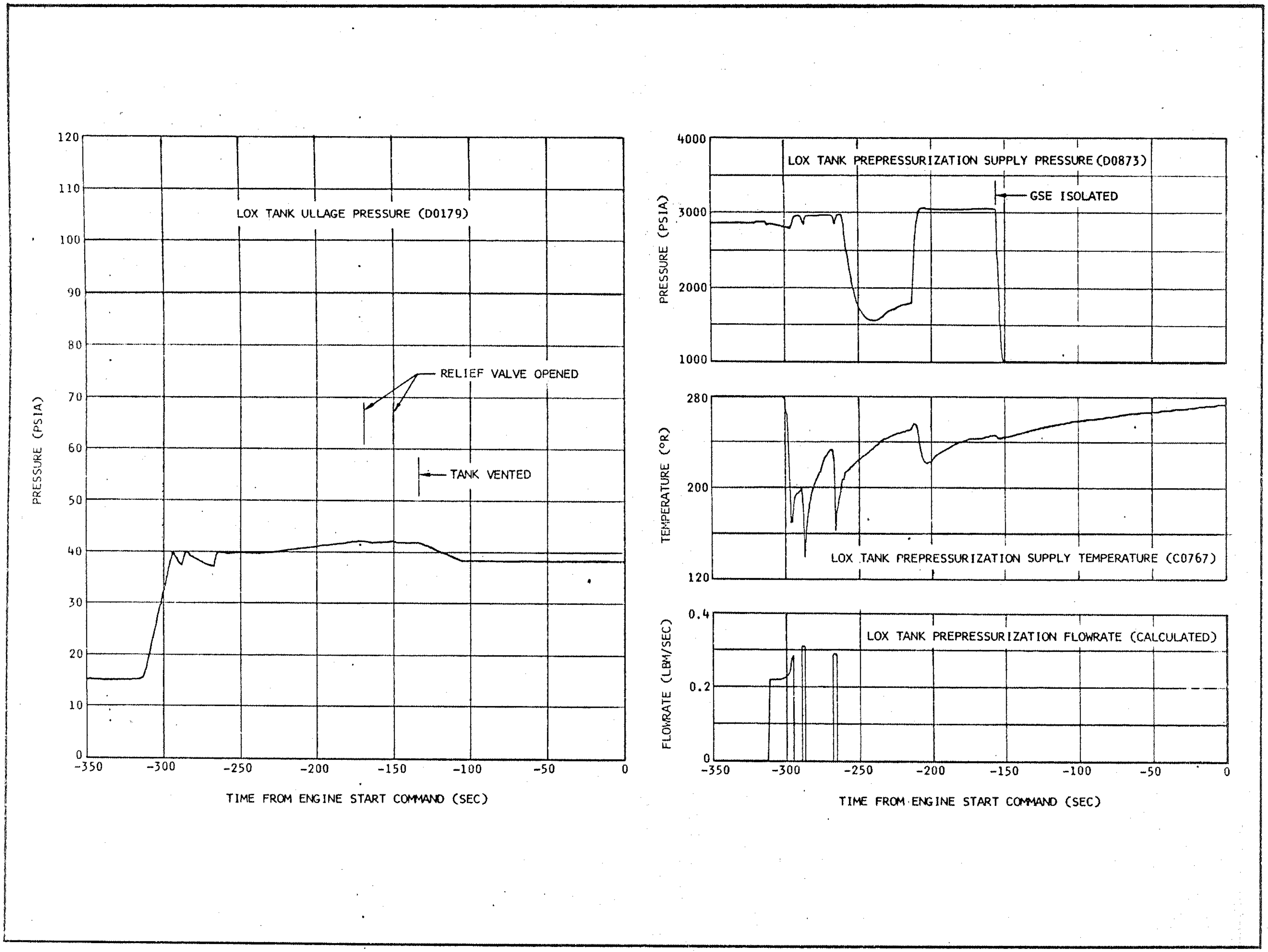

Figure 7-2. LOX Tank Prepressurization

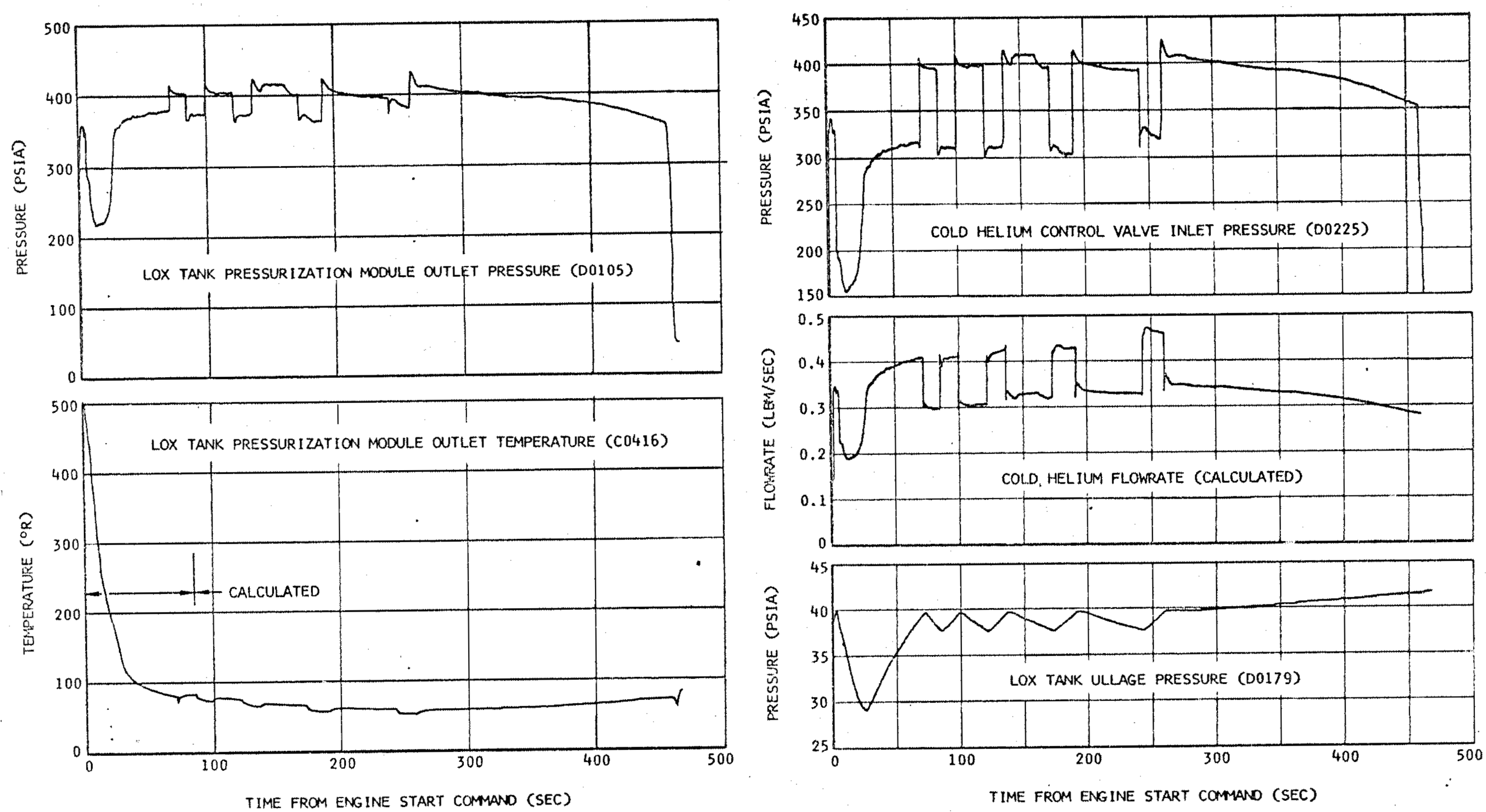

Figure 7-3. LOX Tank Pressurization System Performance

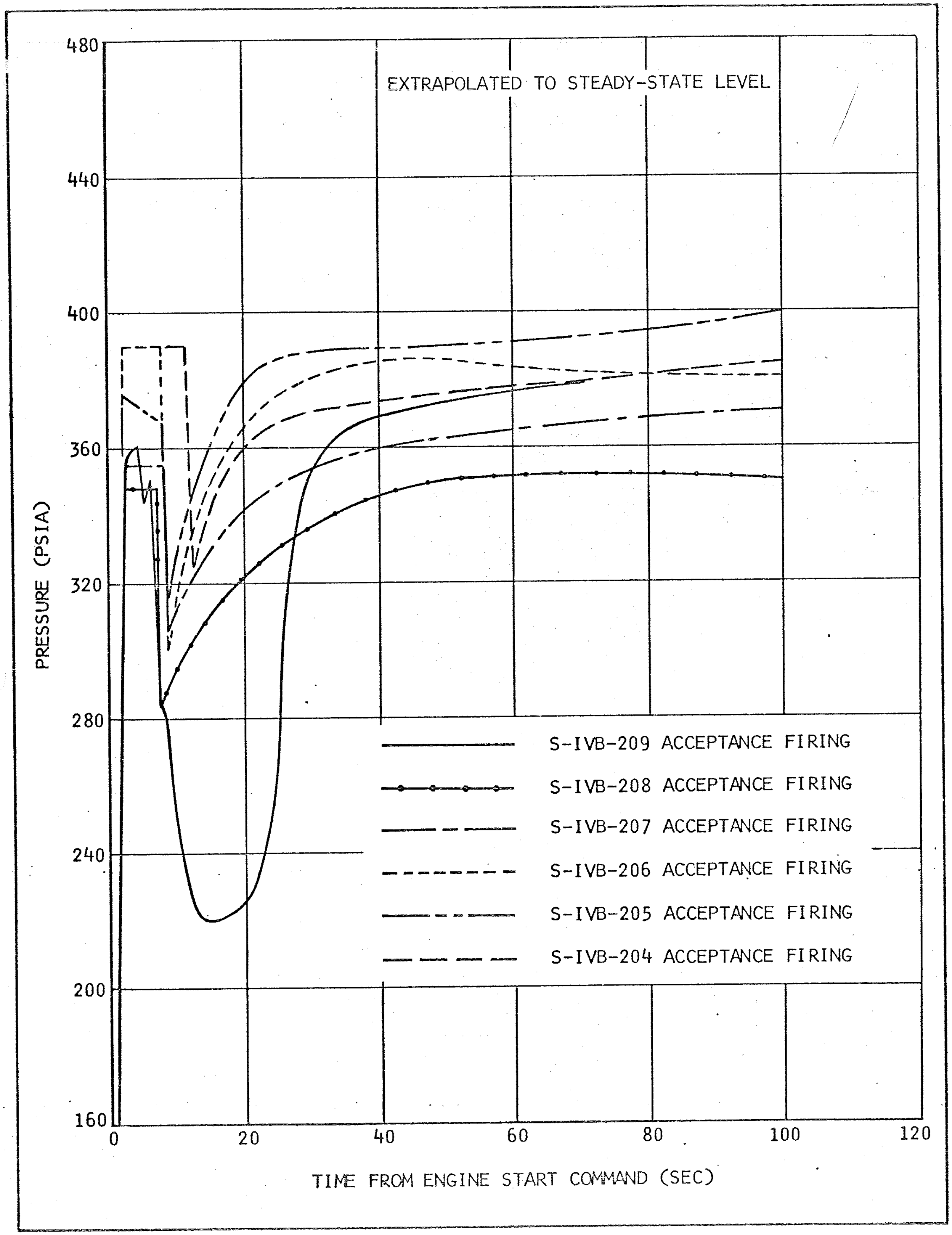

Figure 7-4. LOX Pressurization Module Start Transient Pressure

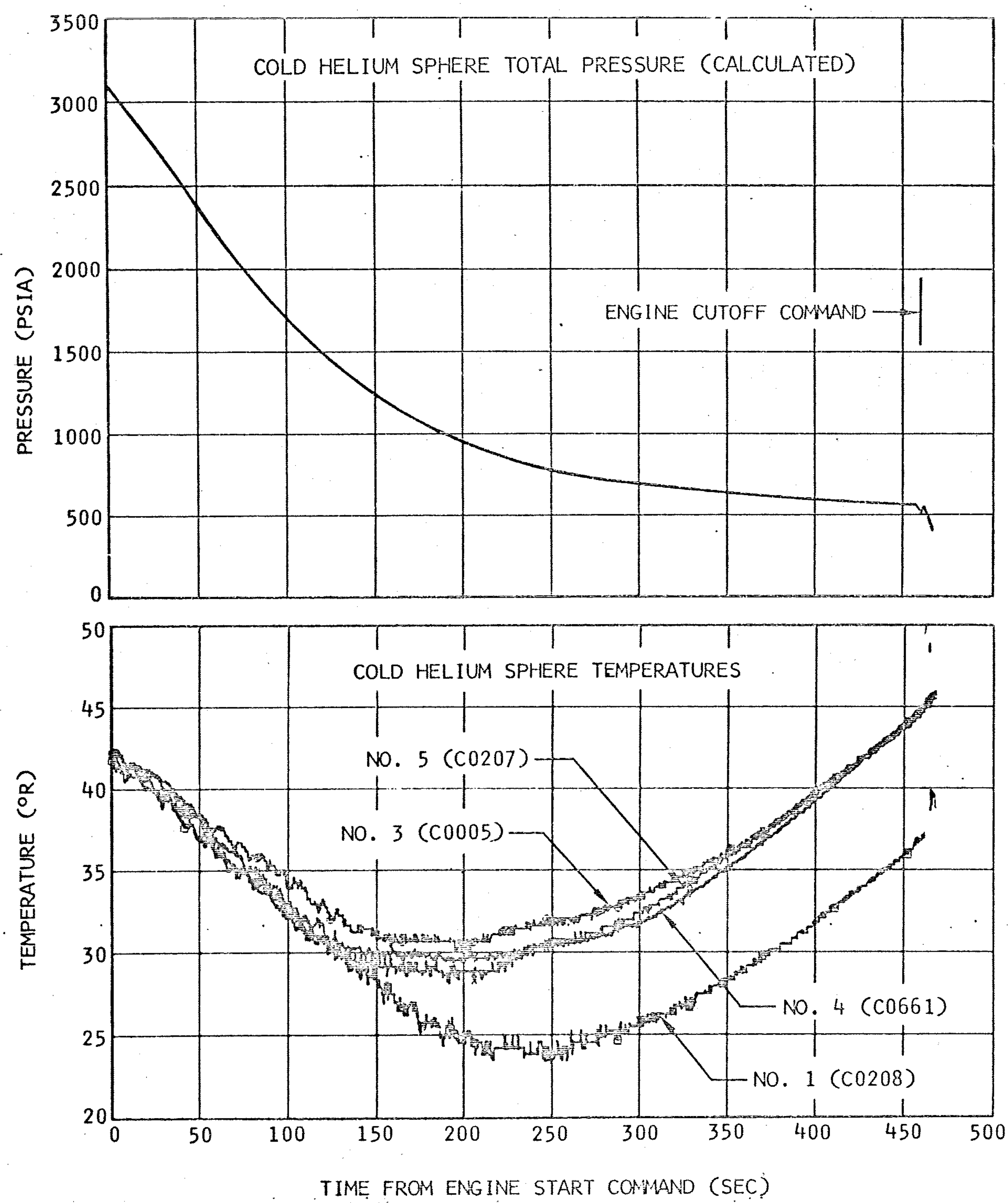

Figure 7-5. Cold Helium Supply

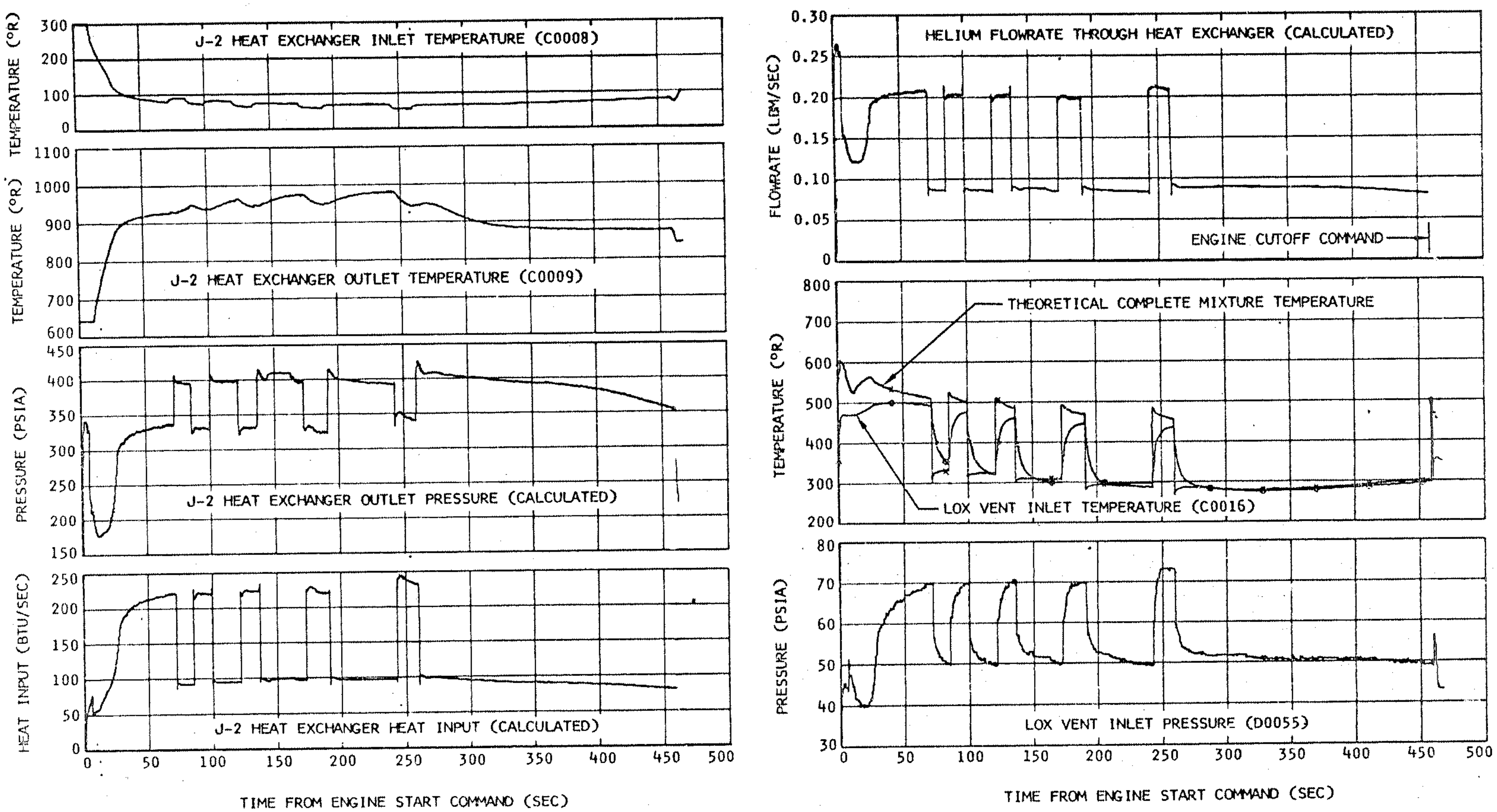

Figure 7-6. J-2 Heat Exchanger Performance

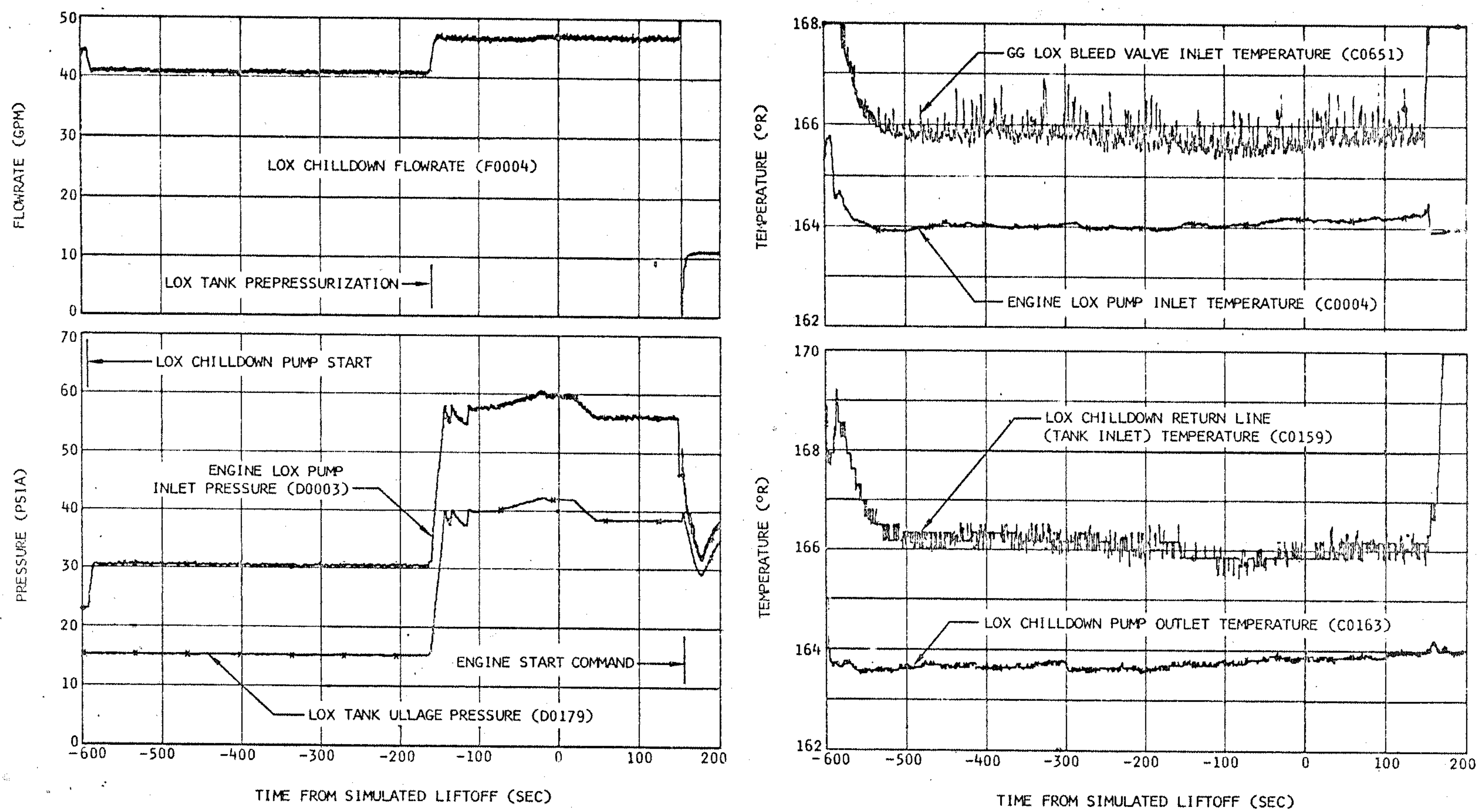

Figure 7-7. LOX Pump Chilldown System Operation

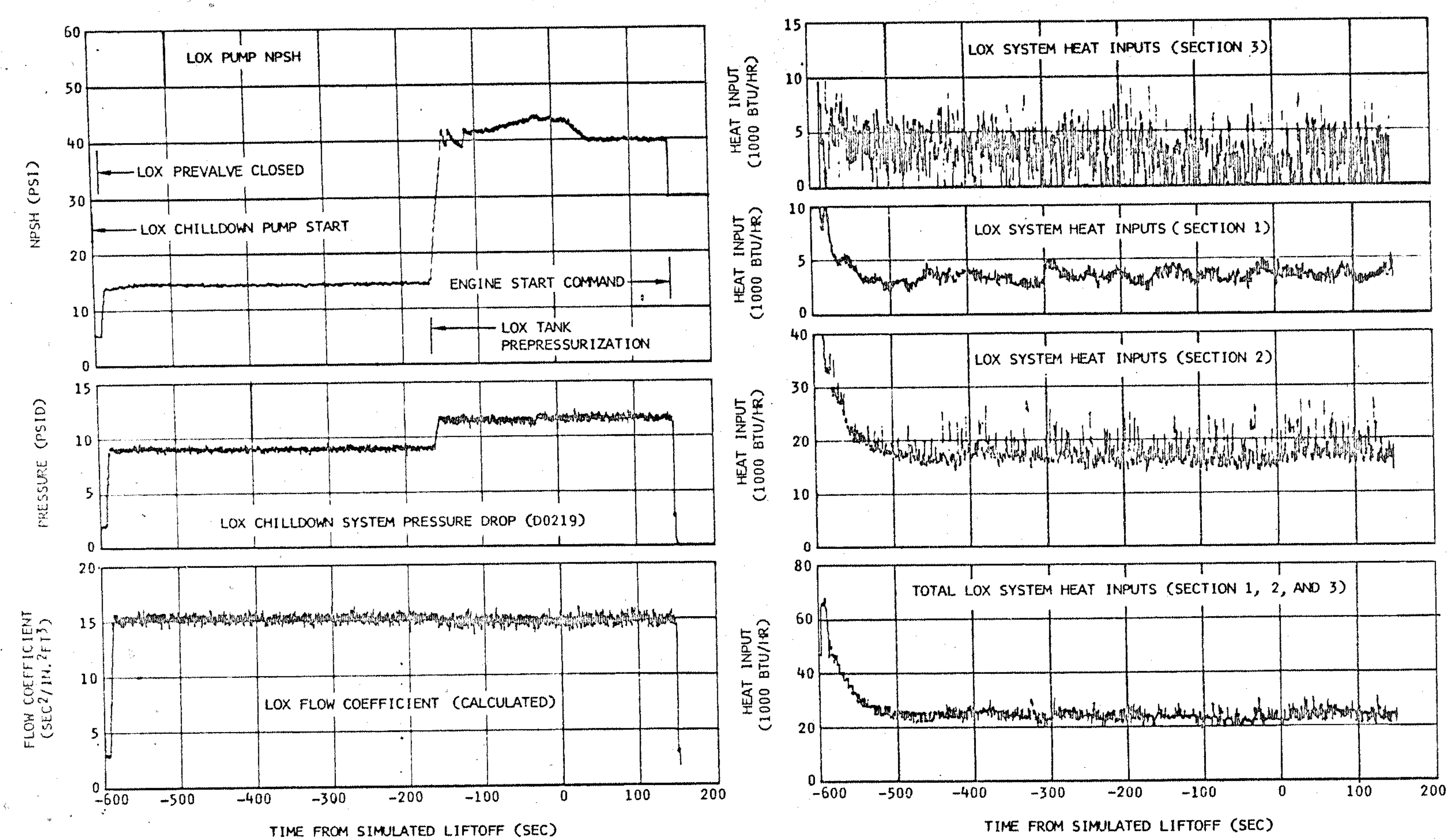

Figure 7-8. LOX Pump Chilldown System Performance

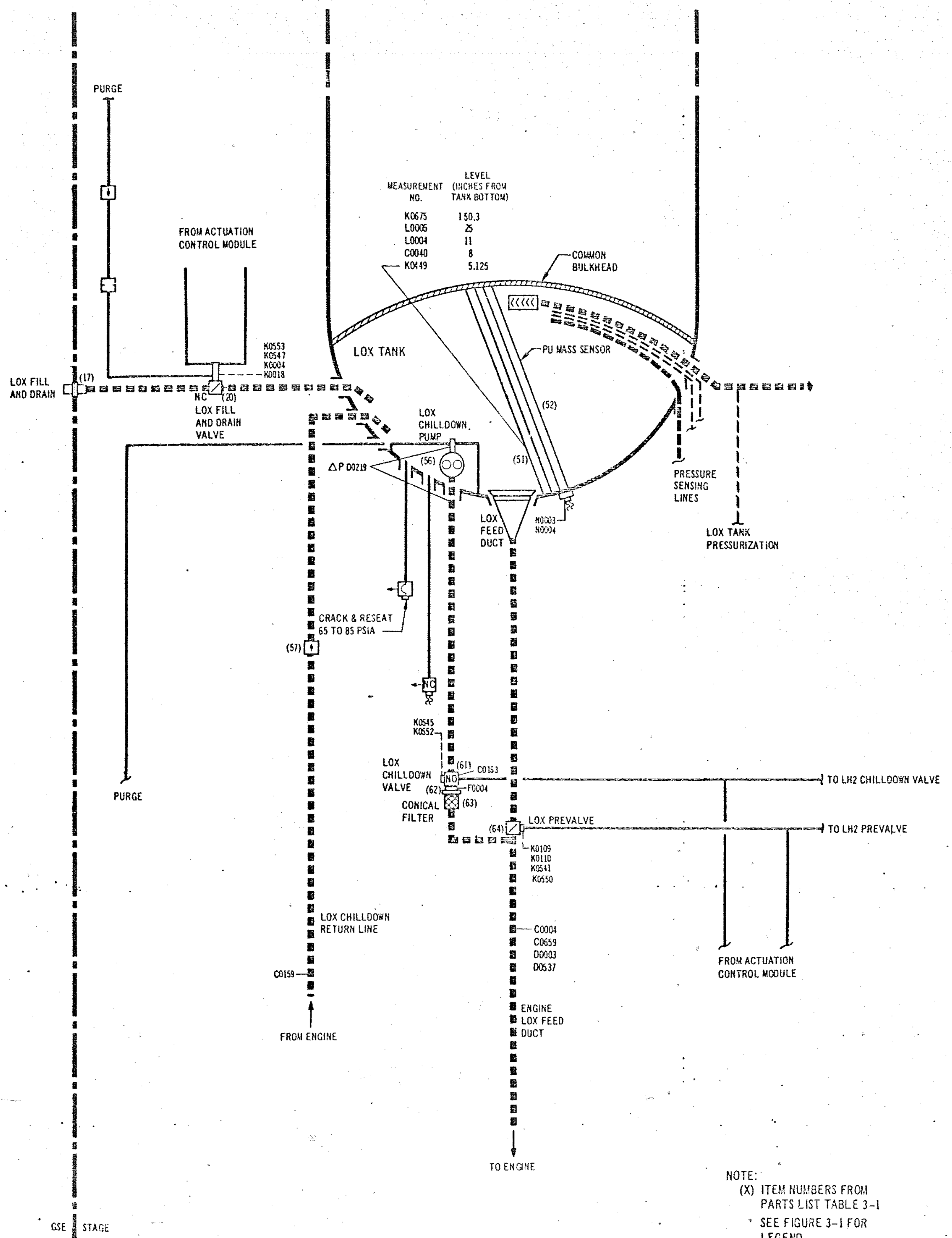

Figure 7-9. LOX Supply System

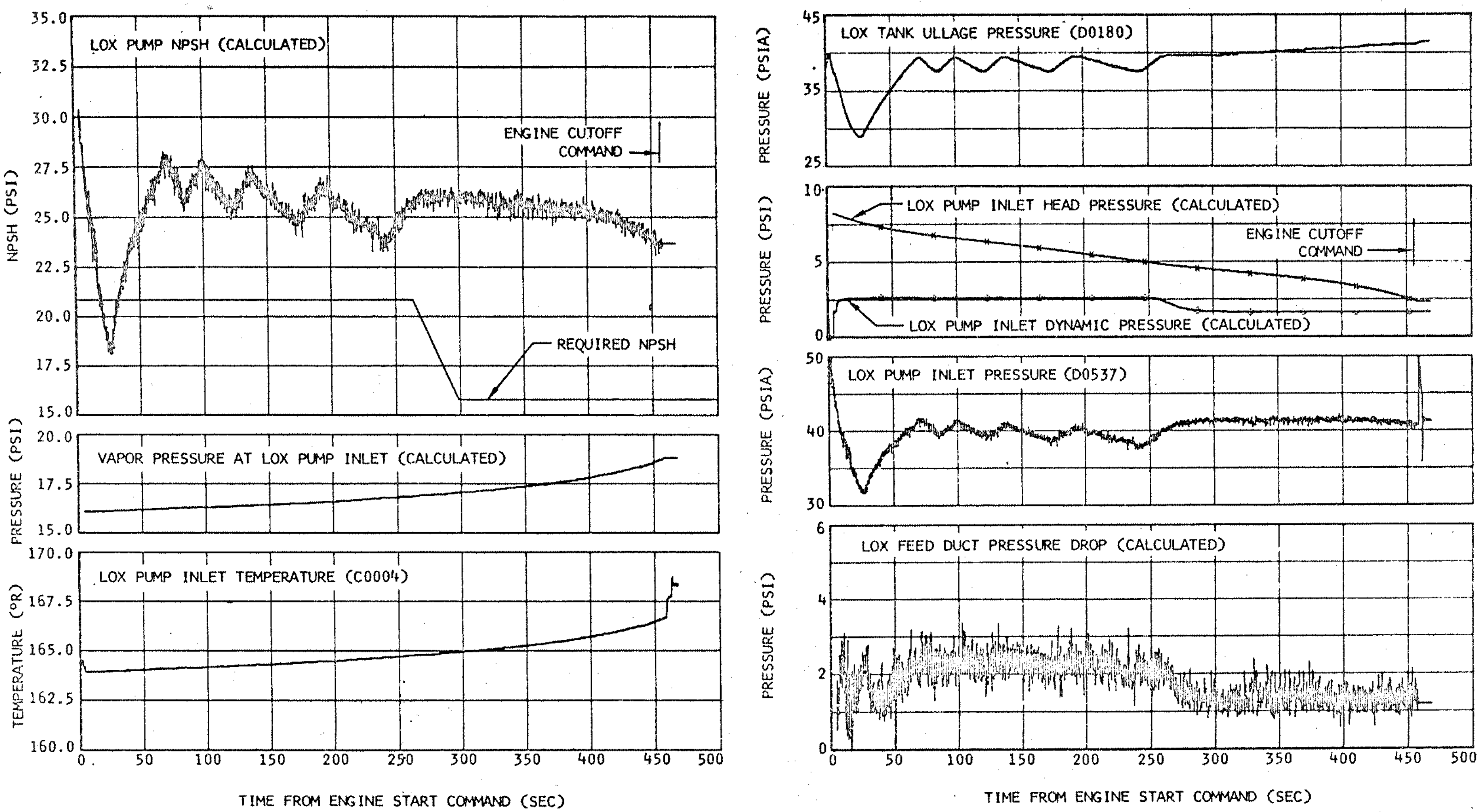

Figure 7-10. LOX Pump Inlet Conditions

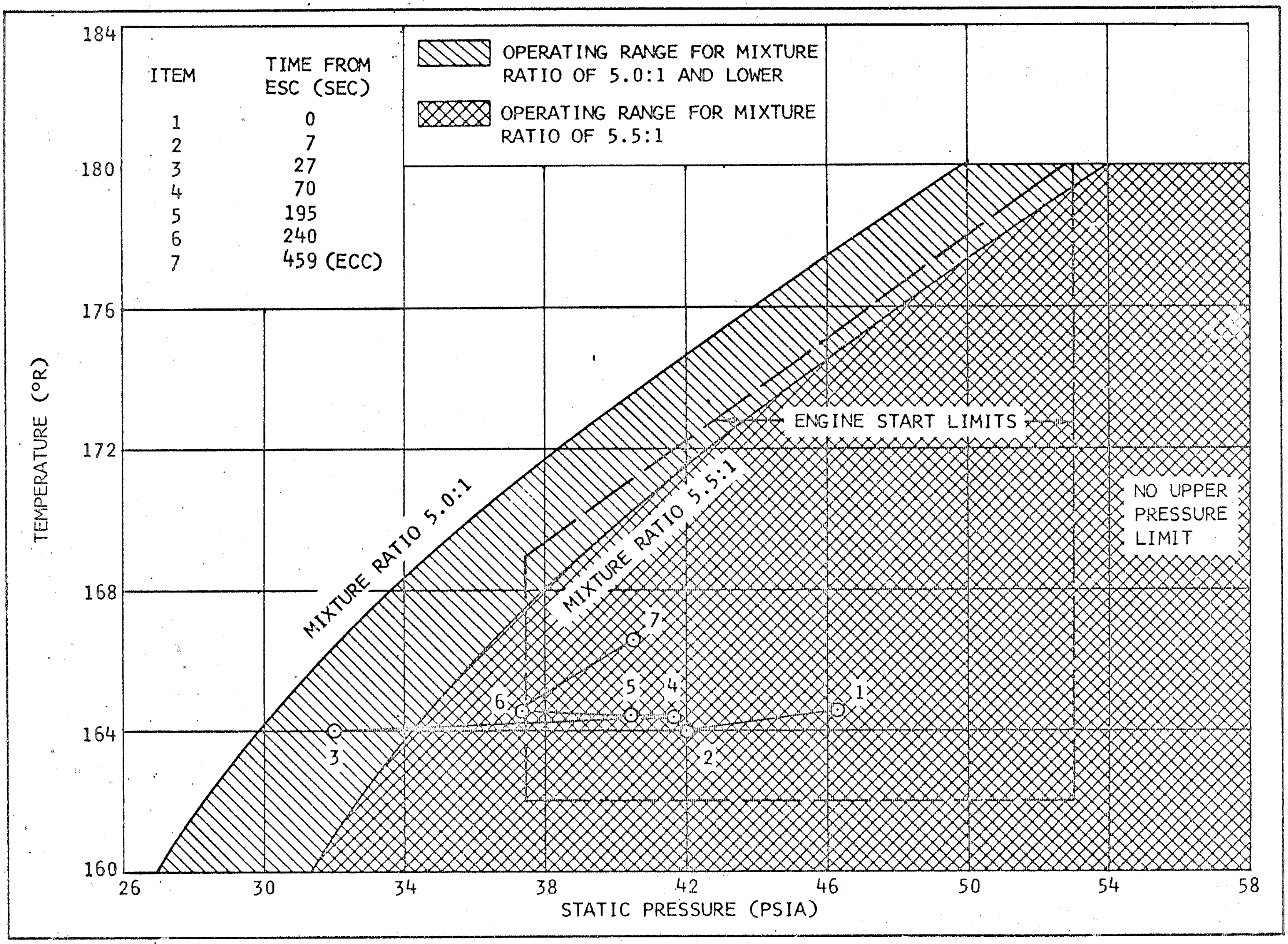

Figure 7-11. LOX Pump Inlet Conditions During Firing

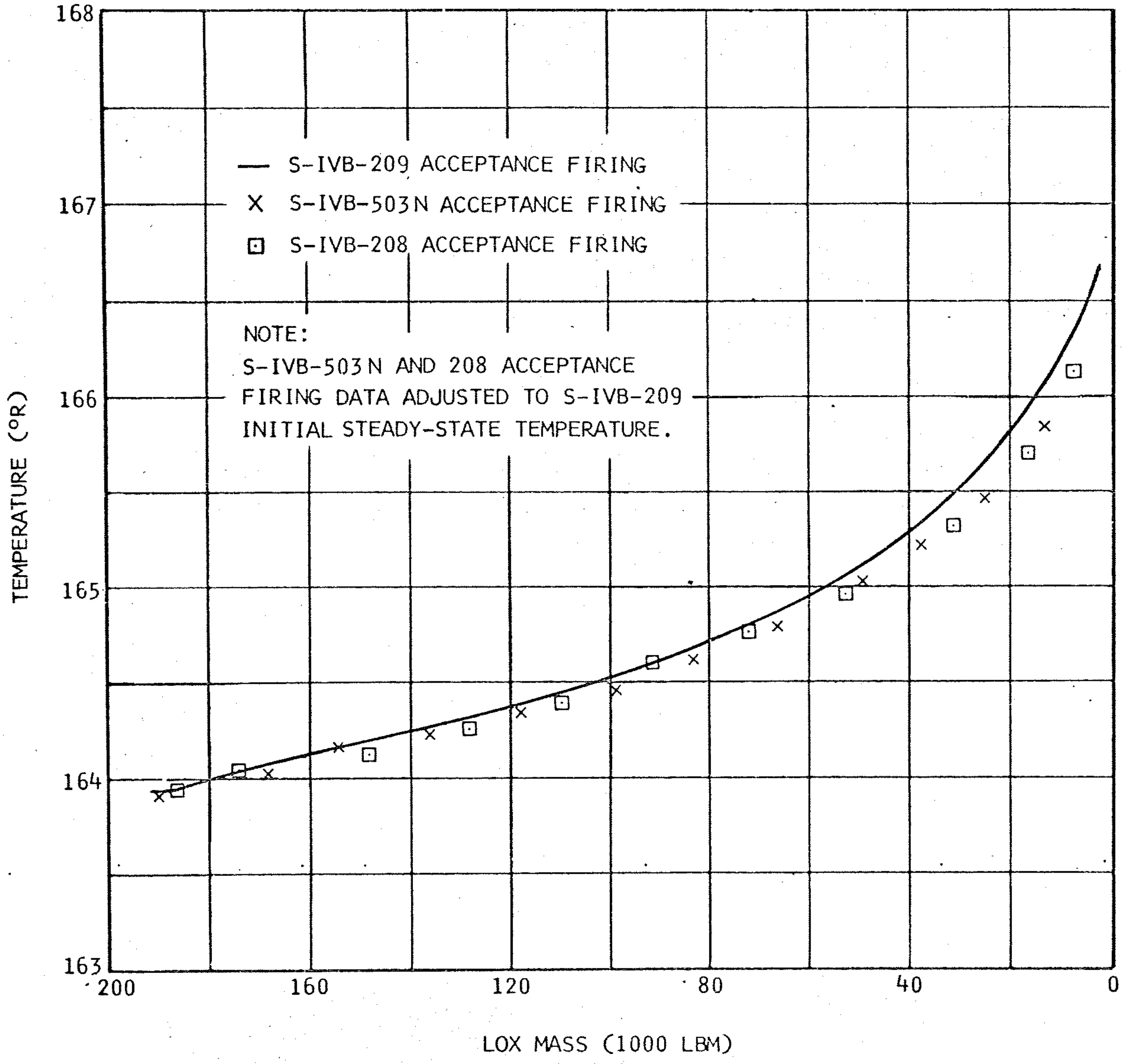

Figure 7-12. Effect of LOX Mass Level on LOX Pump Inlet Temperature

8

FUEL SYSTEM

8. FUEL SYSTEM

The fuel system performed as designed and supplied LH2 to the engine within the limits defined in the engine specification.

8.1 Pressurization Control

The LH2 tank pressurization system (figure 8-1) performed adequately and satisfactorily controlled LH2 tank ullage pressure throughout the firing.

8.1.1 Prepressurization

The LH2 tank was satisfactorily prepressurized with helium from ground support equipment console "B." Data are presented in figure 8-2 and compared with S-IVB-207 and S-IVB-208 data in table 8-1. Between the end of prepressurization and Engine Start Command (ESC), the ullage temperature increased because of ambient heat input, causing the ullage pressure increase shown in figure 8-2.

8.1.2 Pressurization

During engine operation, LH2 tank pressurization was satisfactorily accomplished by the GH2 tapoff system (figure 8-1). The data are presented in table 8-2 and figure 8-3 and show that all measured parameters were within the normal dispersion range observed in previous tests. Two complete overcontrol cycles were accomplished before step pressurization. The LH2 tank relief valve cracked open at ESC +442.7 sec, during step pressurization, and continued relieving until Engine Cutoff Command (ECC).

8.2 LH2 Pump Chilldown

The LH2 pump chilldown system performed satisfactorily; the NPSH at Engine Start Command was well above the required level. The chilldown system data and the results of the performance calculations are presented in figures 8-4 and 8-5 and compared with previous test data in table 8-3.

Examination of the data during the quiescent period before recirculation was initiated revealed that the liquid in the system was saturated at that time. LH2 chilldown flowrate (F0005), LH2 chilldown pump differential pressure (D0218), LH2 pump inlet pressure (D0536), LH2 pump inlet temperature (C0003), LH2 bleed valve temperature (C0650), and LH2 return line temperature (C0161) were biased based on known conditions at that time.

The test utilized the anticipated flight sequence, with chilldown initiated at approximately T_0 -595 sec (paragraph 7.4) and the chilldown shutoff valve open after chilldown termination. The valve was closed at approximately T_0 +602.8 sec. Chilldown system performance was nominal and compared well with that of previous stages, as indicated in table 8-3. System flowrates and temperatures were at the levels anticipated. During unpressurized chilldown, the liquid was subcooled through the system to a point between the engine pump inlet and the bleed valve; the system became entirely subcooled during prepressurization. The high heat leak condition that occurred on the S-IVB-207 and S-IVB-208 stages did not recur.

It should be noted that during the post-acceptance firing tests, the LH2 chilldown duct vacuum and the LH2 upper low pressure duct vacuum exceeded 1,000 microns. No detrimental effect was noted in the chilldown system performance; both of these ducts were subsequently replaced.

Because of the problems during the S-IVB-207 and S-IVB-208 stage acceptance firings and because available data were inadequate for developing a satisfactory explanation, additional instrumentation was installed on the S-IVB-209 stage and two special chilldown tests were performed. During the prefiring period of CD 614084, the chilldown operation was performed repeatedly while the flowrate of the chilldown fairing helium purge was varied. After the acceptance firing had been completed, CD 614086 was initiated on 23 June. During this test, the environment inside the chilldown fairing was varied between helium and GN2 and controlled within known limits.

8.3 Engine LH2 Supply

The engine LH2 supply system (figure 8-6) satisfactorily supplied LH2 to the engine pump inlet throughout engine operation and maintained the pressure and temperature within a range that provided an NPSH above the minimum requirement. The data and the results of the performance calculations are presented in figure 8-7 and compared with data from two previous acceptance firings in table 8-4.

The LH2 pump inlet pressure and temperature were plotted in the engine operating region (figure 8-8) and showed that the LH2 pump inlet conditions were met satisfactorily throughout the firing. Figure 8-9 is a plot of the pump inlet temperature versus the mass remaining in the LH2 tank during burn. It includes data from S-IVB-208 and S-IVB-503N acceptance firings biased to an identical initial condition to correct for instrumentation error, different heating rates during prepressurization, and other test-to-test variations. The data from all three firings agree closely.

8.4 LH2 Vent and Relief Valve Performance

During the vent and relief valve check during CD 614084, the LH2 vent and relief valve relieved at 38.0, 37.9, and 37.9 psia. During the acceptance firing (CD 614085), the valve feathered open at 37.7 psia.

TABLE 8-1
LH2 TANK PREPRESSURIZATION DATA

PARAMETER	S-IVB-207	S-IVB-208	S-IVB-209
Prepressurization duration (sec)	71.6	77.5	49.0
Helium mass used during prepressurization (lbm)	38.72	33.76	24.6
Ullage pressure			
At prepressurization termination (psia)	34.1	33.4	33.5
At simulated liftoff (psia)	34.7	33.9	34.1
At Engine Start Command (psia)	37.4	36.4	36.5
Rise rate after prepressurization (psi/min)	1.04	0.99	0.84
Events (sec from T_0)			
Prepressurization initiation	-110.7	-109.6	-110.7
Prepressurization termination	-39.1	-32.1	-61.7

TABLE 8-2
LH2 TANK PRESSURIZATION DATA

PARAMETER	S-IVB-207	S-IVB-208	S-IVB-209
Number of control cycles	2	2	2
Control pressure switch range (psia)	27.1 to 29.3	27.3 to 29.0	27.3 to 29.3
Ullage pressure			
At Engine Start Command (psia)	37.4	36.4	36.5
At step pressurization (psia)	28.5	28.2	28.0
At Engine Cutoff Command (psia)	38.9	37.3	37.8
At relief valve operation (psia)	38.35	N/A	37.7
GH2 pressurant flowrate			
Undercontrol (lbm/sec)	0.36	0.40	0.36
Overcontrol (lbm/sec)	0.65	0.68	0.63
Step before cutback (lbm/sec)	1.10	1.18	N/A
Step after cutback (lbm/sec)	0.99	1.08	0.98
Total GH2 pressurant mass (lbm)	281.2	285.1	280.3
LH2 boiloff during engine operation (lbm)	0	0	0
Events (sec from ESC)			
Step pressurization	301.3	300.2	300.2
Relief valve opening	408	N/A	442.7

N/A = Not applicable

TABLE 8-3 (Sheet 1 of 2)
LH2 CHILLDOWN SYSTEM PERFORMANCE

PARAMETER	S-IVB-206	S-IVB-209
NPSH (psi)		
Maximum	25.5	21.9
At Engine Start Command	18.0	14.2
Minimum required at Engine Start Command	6.4	6.5
Average flow coefficient ($sec^2/in.^2ft^3$)	18.2	17.5
Fuel quality (sections 2 and 3--unpressurized)		
Maximum (lb gas/lb mixture)	0.033	0.045
At prepressurization (lb gas/lb mixture)	0.025	0.034
Pump inlet conditions at engine start		
Static pressure (psia)	38.5	37.3
Temperature (deg R)	38.6	39.4
Amount of subcooling (deg R)	4.6	3.5
Heat absorption rate--unpressurized (Btu/hr)		
Section 1 (tank to pump inlet)	21,000	20,000
Sections 2 (pump inlet to bleed valve) and 3 (bleed valve to tank)	18,000	23,000
Total	39,000	43,000
Heat absorption rate--pressurized (Btu/hr)		
Section 1	17,500	21,000
Section 2	22,000	23,300
Section 3	21,500	15,000
Total	61,000	59,300
Chilldown flowrate (gpm)		
Unpressurized	108	102
Pressurized	143	142.6

TABLE 8-3 (Sheet 2 of 2)
LH2 CHILLDOWN SYSTEM PERFORMANCE

PARAMETER	S-IVB-206	S-IVB-209
Pressure drop (psi)		
Unpressurized	9.4	9.4
Pressurized	8.0	8.0
Events (sec from T_0)		
Chilldown start	-305.1	-595.1
Prevalve closed	-301.8	-591.1
Prepressurization	-110.1	-110.7
Prevalve Open Command	147.22	147.6
Chilldown pump off	150.2	151.6
Chilldown shutoff valve closed	150.34	602.8
Engine Start Command	150.77	151.847

TABLE 8-4
LH2 PUMP INLET CONDITIONS

PARAMETER	S-IVB-207	S-IVB-208	S-IVB-209
Pump inlet conditions at engine start			
Static pressure (psia)	38.2	38.1	37.3
Temperature (deg R)	41.6	41.4	39.4
NPSH requirements			
At high EMR (psi)	5.8	6.5	6.6
After EMR cutback (psi)	5.6	5.9	6.05
NPSH available			
At Engine Start Command (psi)	6.8	7.6	19.5
At Engine Cutoff Command (psi)	16	16	15.8
Minimum (psi)	9.5	9.5	8.25
Time of minimum (sec from ESC)	270	215	300
Feed duct at high EMR			
Pressure drop (psi)	0.5	0.5	1.1
Flowrate (lbm/sec)	80.5	85.5	82.8
Feed duct after EMR cutback			
Pressure drop (psi)	0.3	0.5	0.9
Flowrate (lbm/sec)	74.2	79.4	76.1

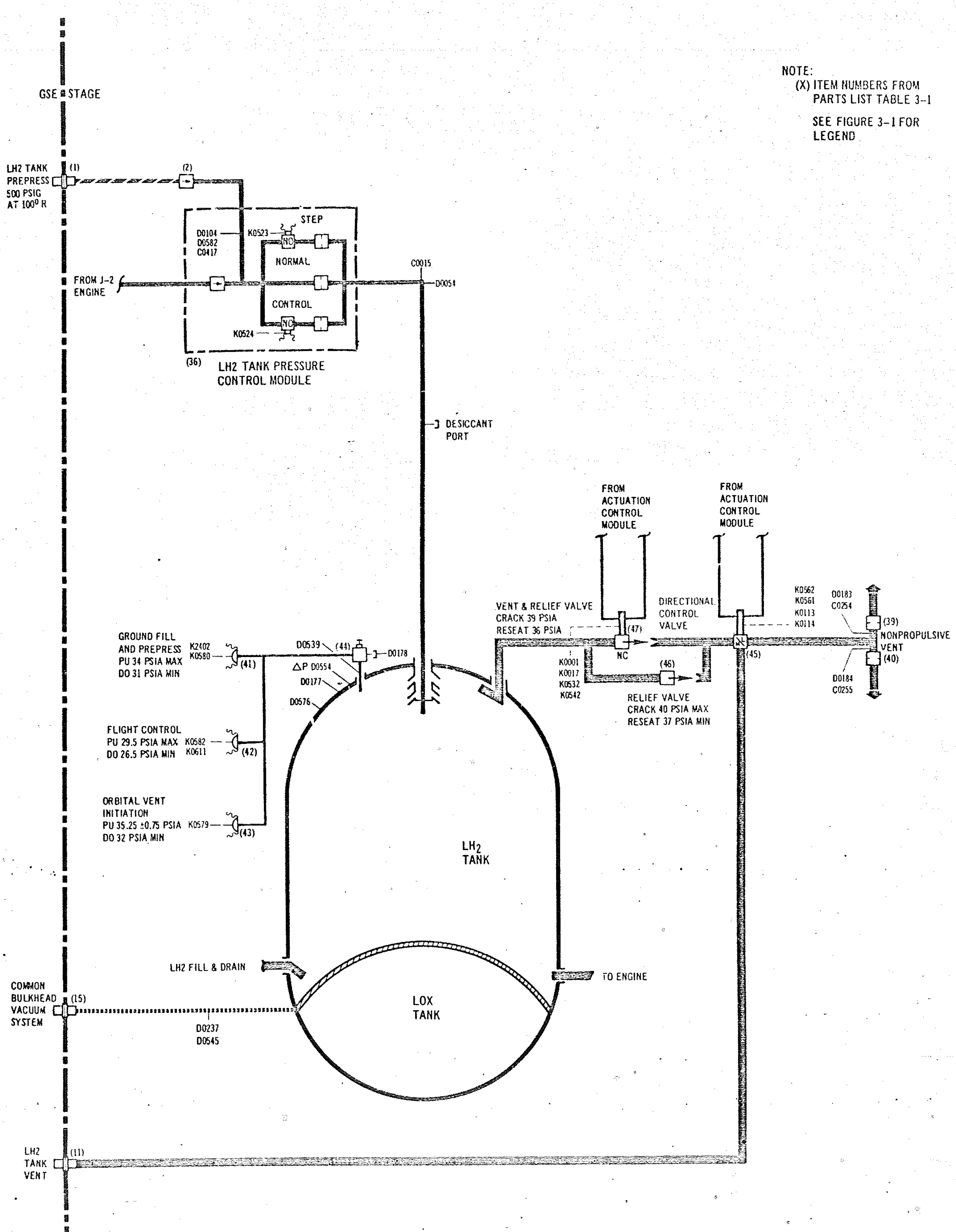

Figure 8-1. LH2 Tank Pressurization System

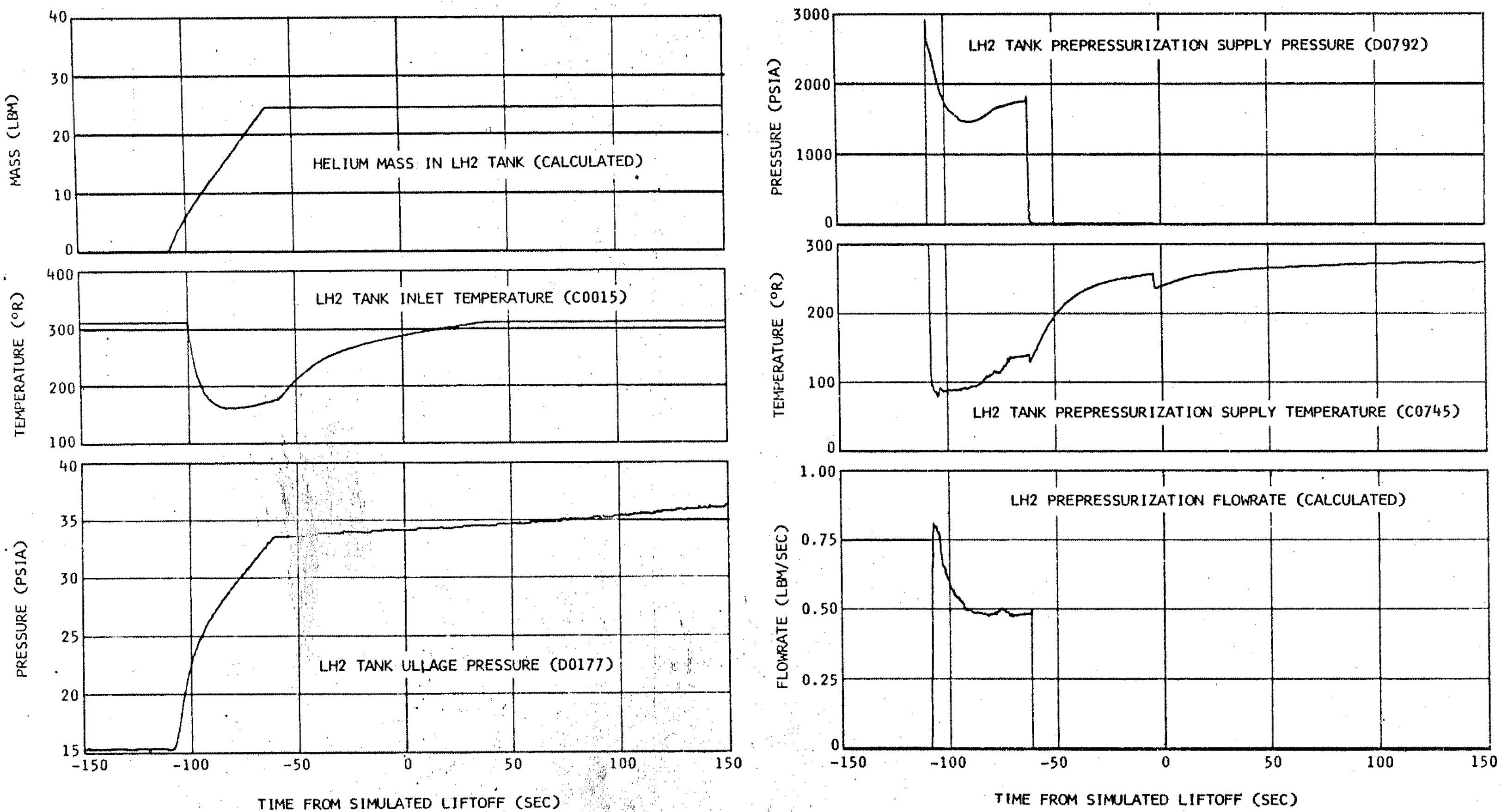

Figure 8-2. LH2 Tank Prepressurization System Performance

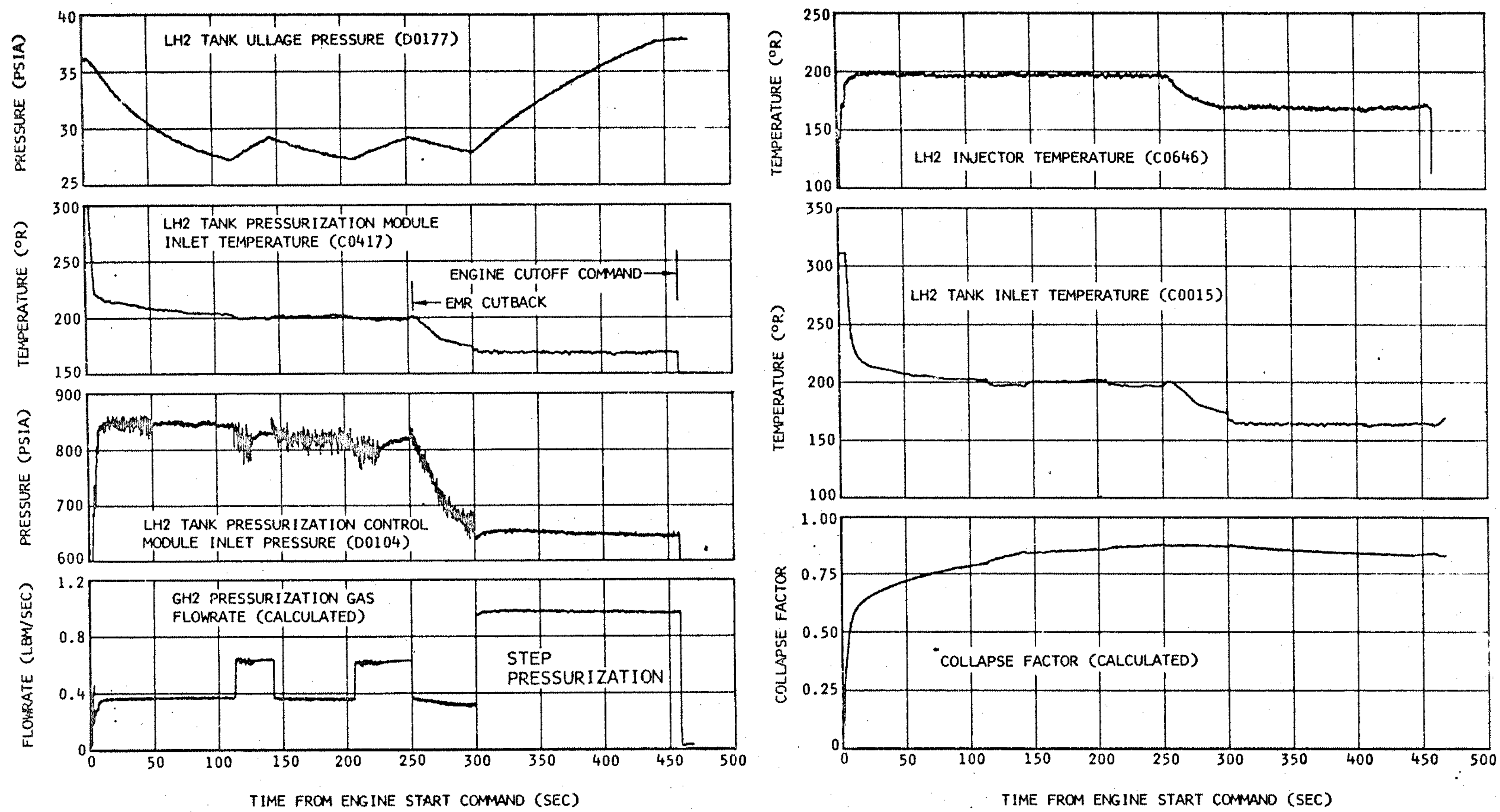

Figure 8-3. LH2 Tank Pressurization System Performance

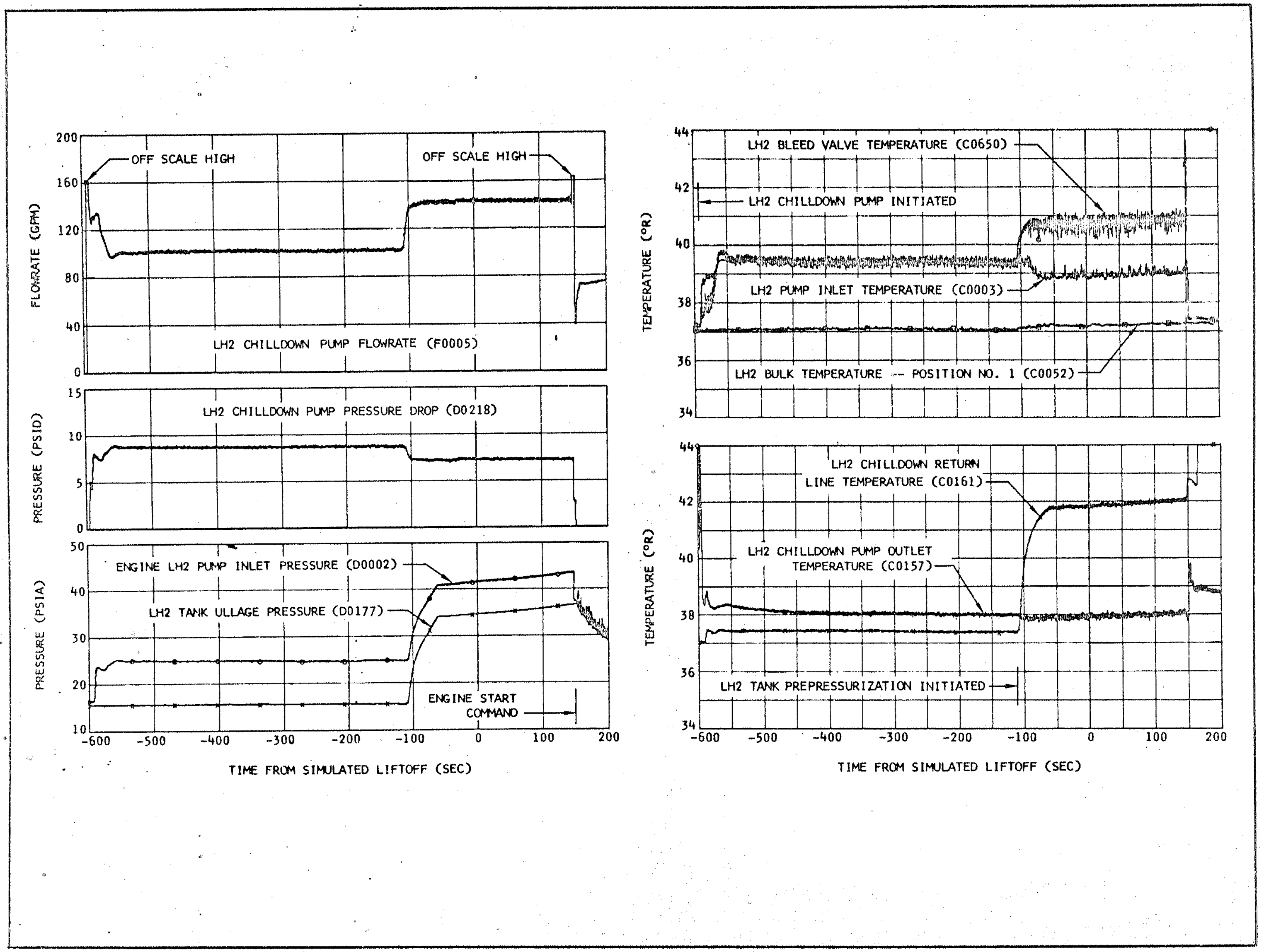

Figure 8-4. LH2 Pump Chilldown

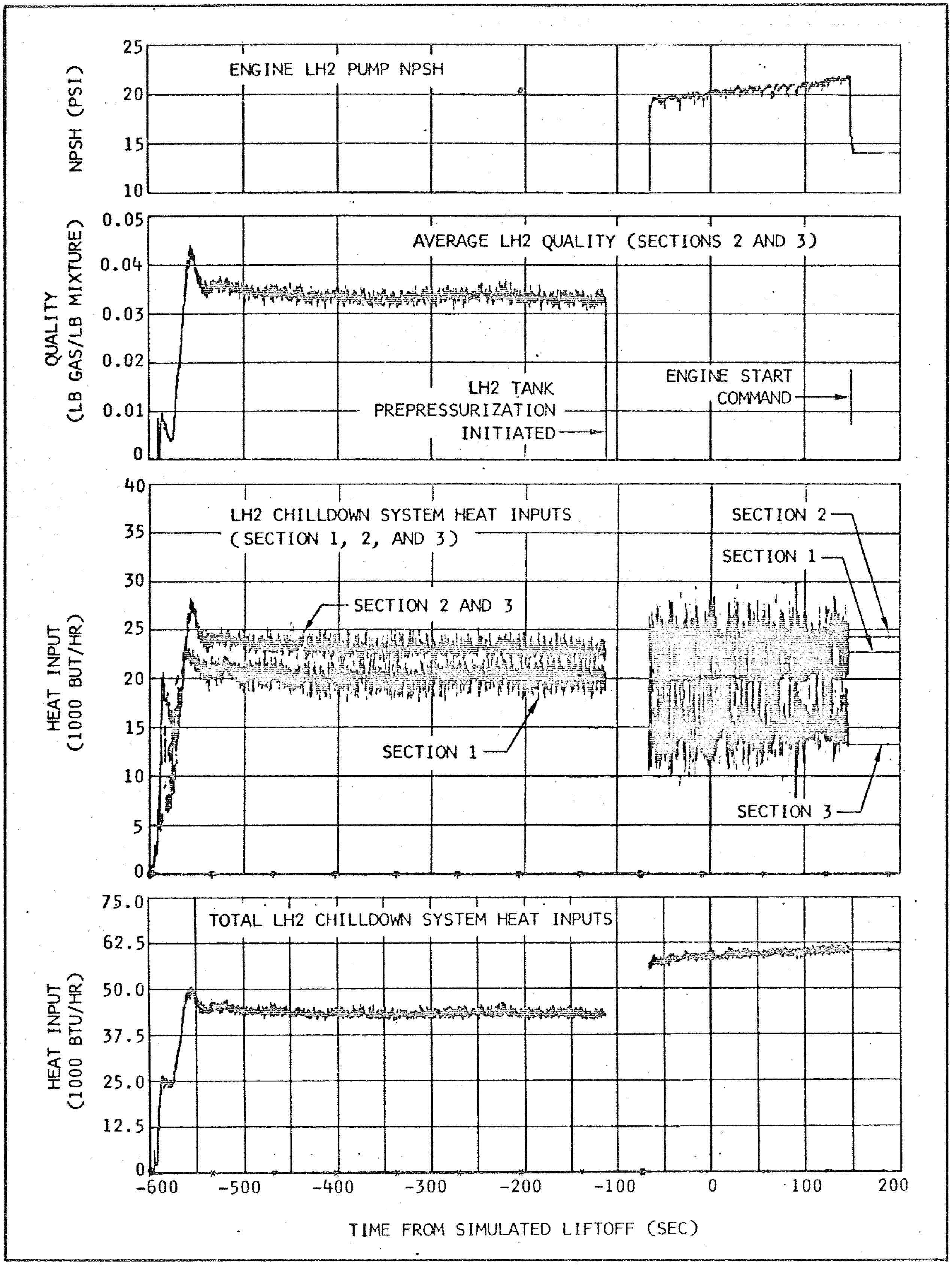

Figure 8-5. LH2 Pump Chilldown Characteristics

NOTE:
(X) ITEM NUMBERS FROM PARTS LIST TABLE 3-1
SEE FIGURE 3-1 FOR LEGEND

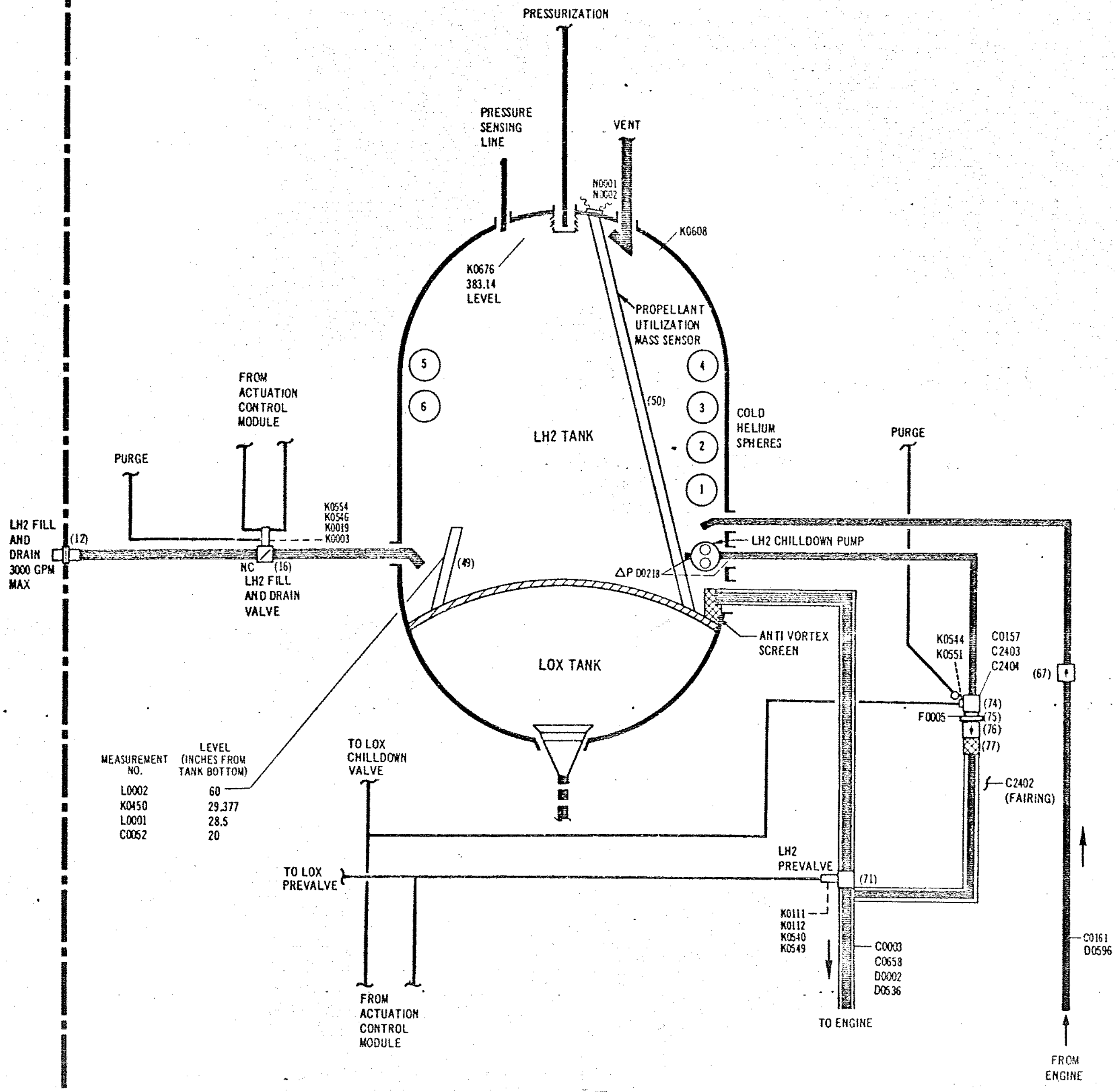

Figure 8-6. LH2 Supply System

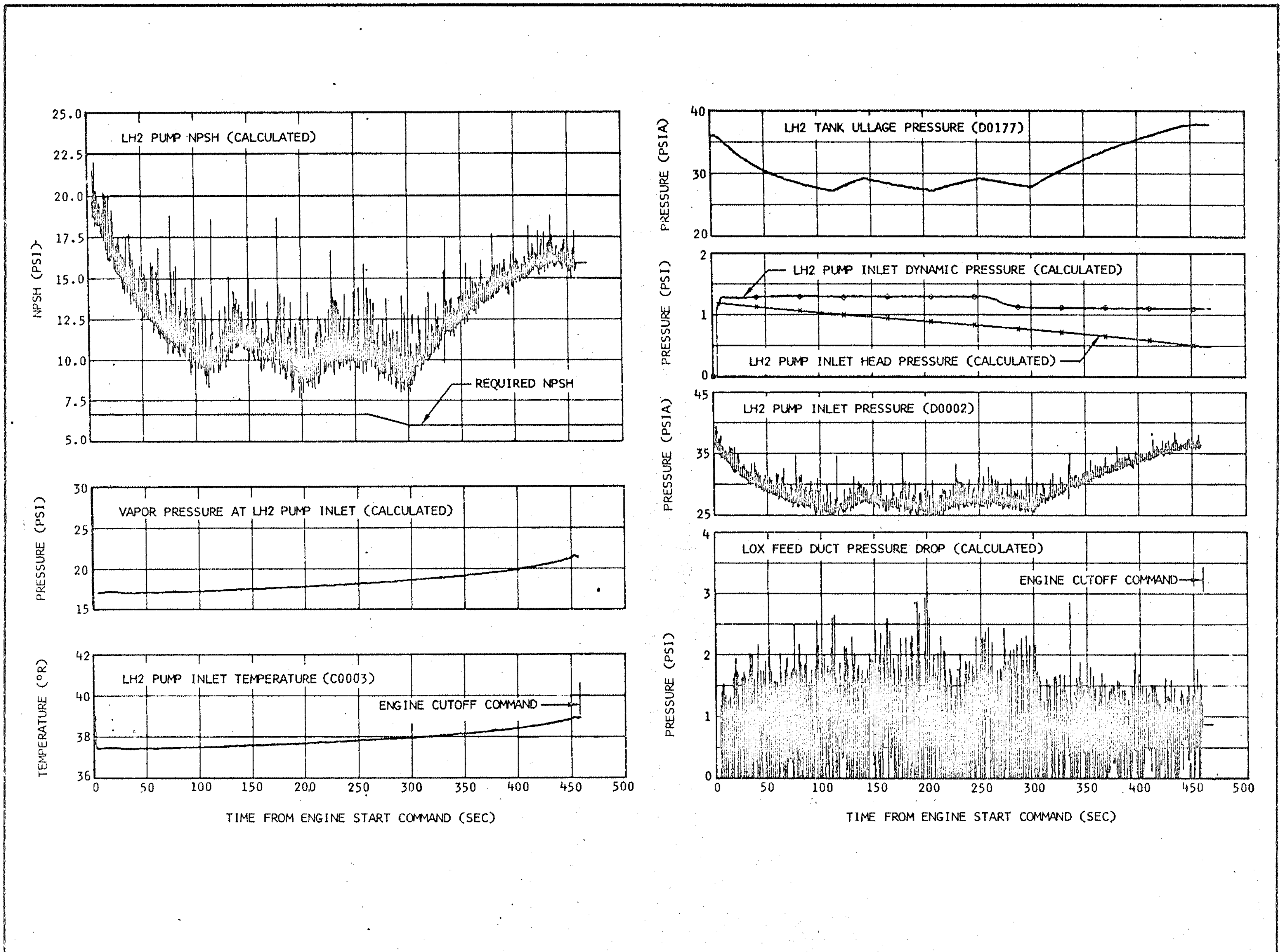

Figure 8-7. LH2 Pump Inlet Conditions

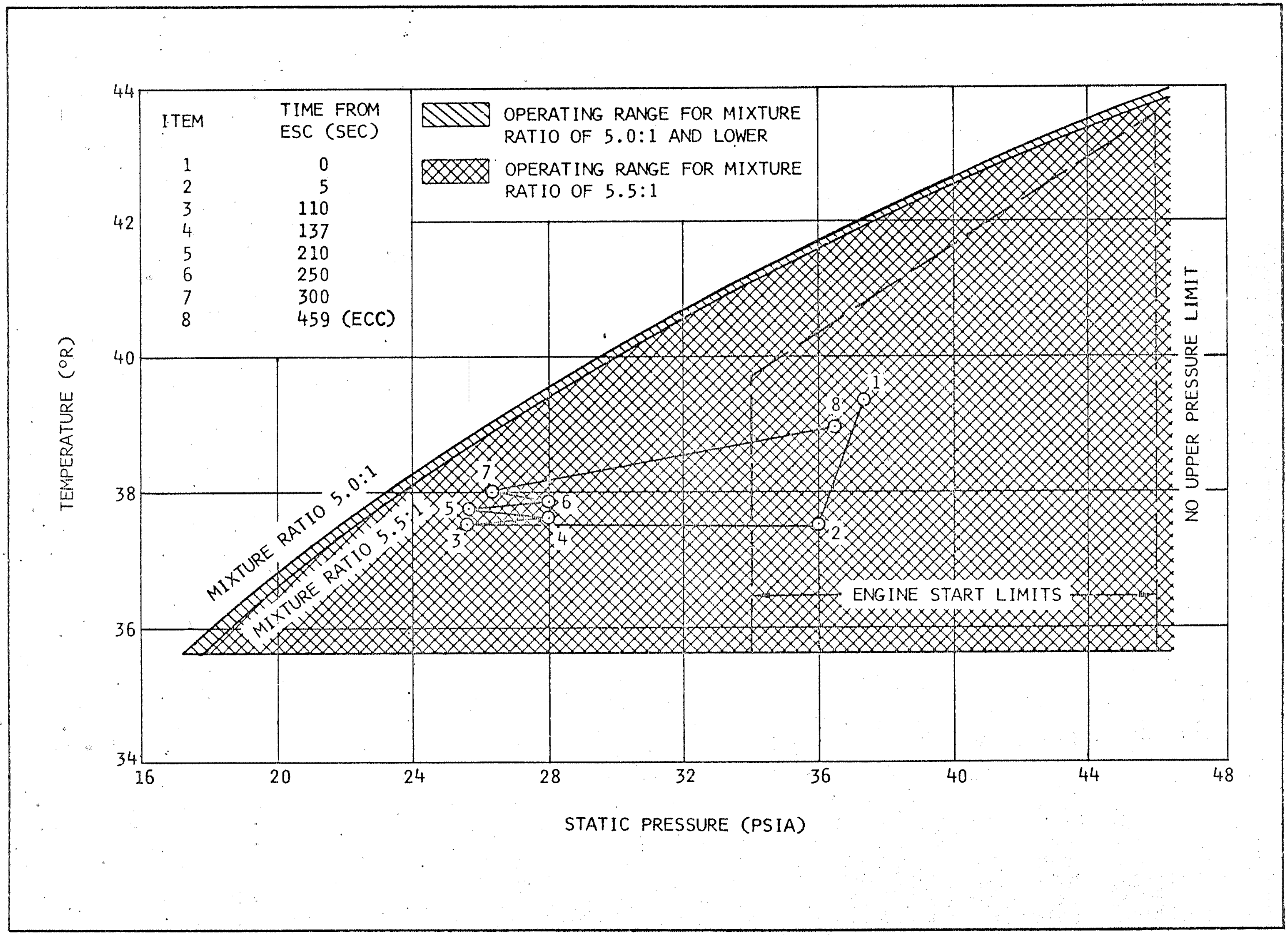

Figure 8-8. LH2 Pump Inlet Conditions During Firing

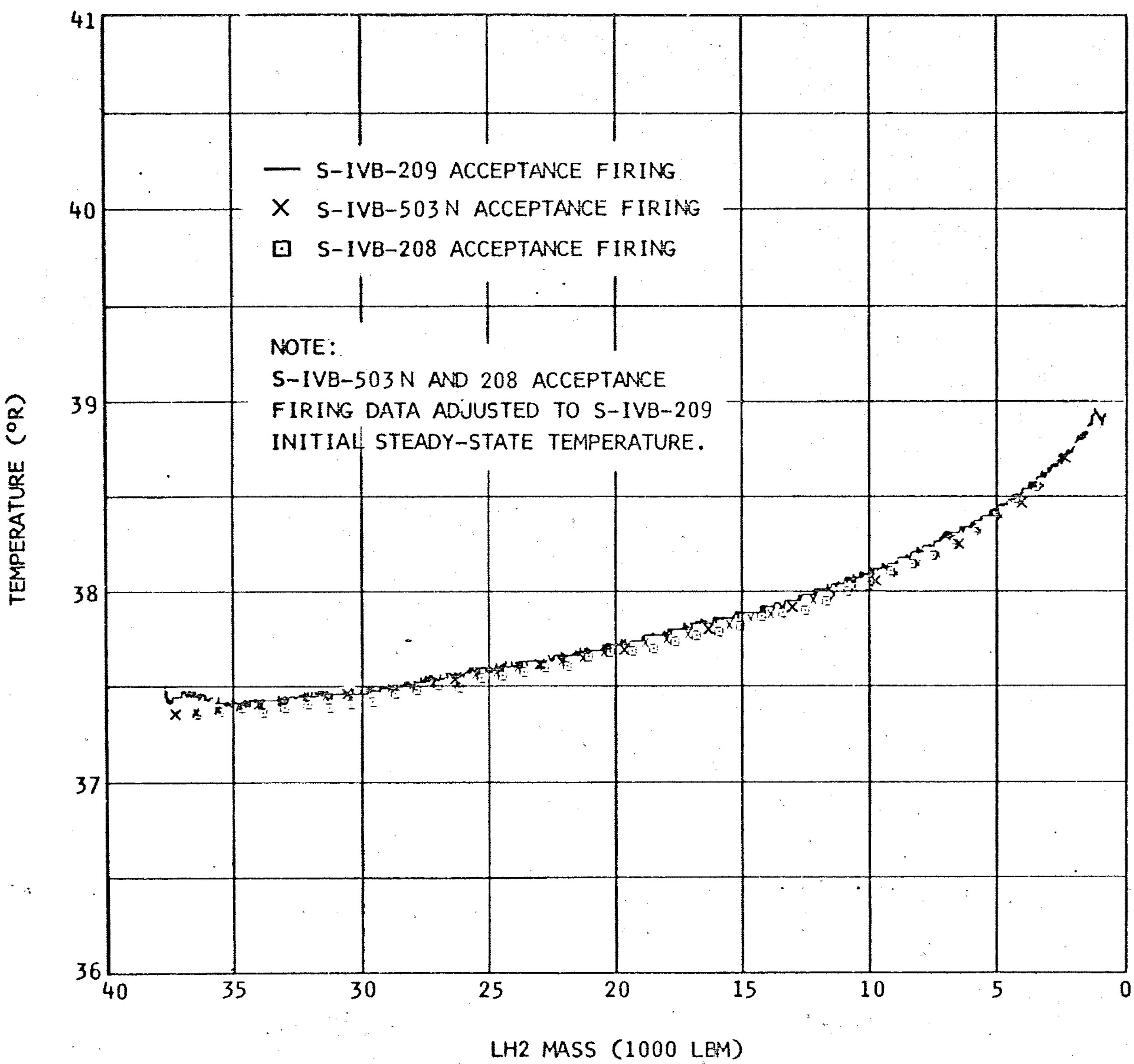

Figure 8-9. Effect of LH2 Mass Level on LH2 Pump Inlet Temperature

9

PNEUMATIC CONTROL
AND PURGE SYSTEM

9. PNEUMATIC CONTROL AND PURGE SYSTEM

The pneumatic control and purge system (figure 9-1) performed satisfactorily throughout the acceptance firing. The helium supply to the system was adequate for both pneumatic valve control and purging; the regulated pressure was maintained within the acceptable limits and all components functioned normally. Because the pneumatic sphere temperature transducer is not installed on operational stages such as S-IVB-209, mass and temperature data cannot be presented. The data that were obtained are presented in figure 9-2.

9.1 Pneumatic Control

With the exception of the LOX prevalve, all engine and stage pneumatically controlled valves responded properly throughout the countdown and acceptance firing. The LOX prevalve opening time was 3.01 sec, 0.01 sec longer than the 3 sec SIM-interrupt time used on previous acceptance firings. During CD 614084 the prevalve opening time was observed to be 2.85 sec; therefore, for CD 614085 the SIM-interrupt time was changed to 4 sec. Part of this increase over the normal 2.2 to 2.5 sec opening time is attributed to a new configuration of the actuation control module. The precise causes of the problem, as well as remedial action, are presently under investigation.

9.2 Ambient Helium Purges

During the acceptance firing, all stage purge functions that utilize stage pneumatics were satisfactorily accomplished. The pneumatic system was isolated from the ground support equipment at T_0 -3 sec, thus discontinuing those purges that were facility supplied. The flowrates of the various purge orifices are listed in table 3-2.

The LOX chilldown motor container purge pressure was maintained within the design range throughout the acceptance firing. The engine pump purge regulator pressure was initially thought to be abnormal; however, the cause was determined to be a faulty transducer (D0050).

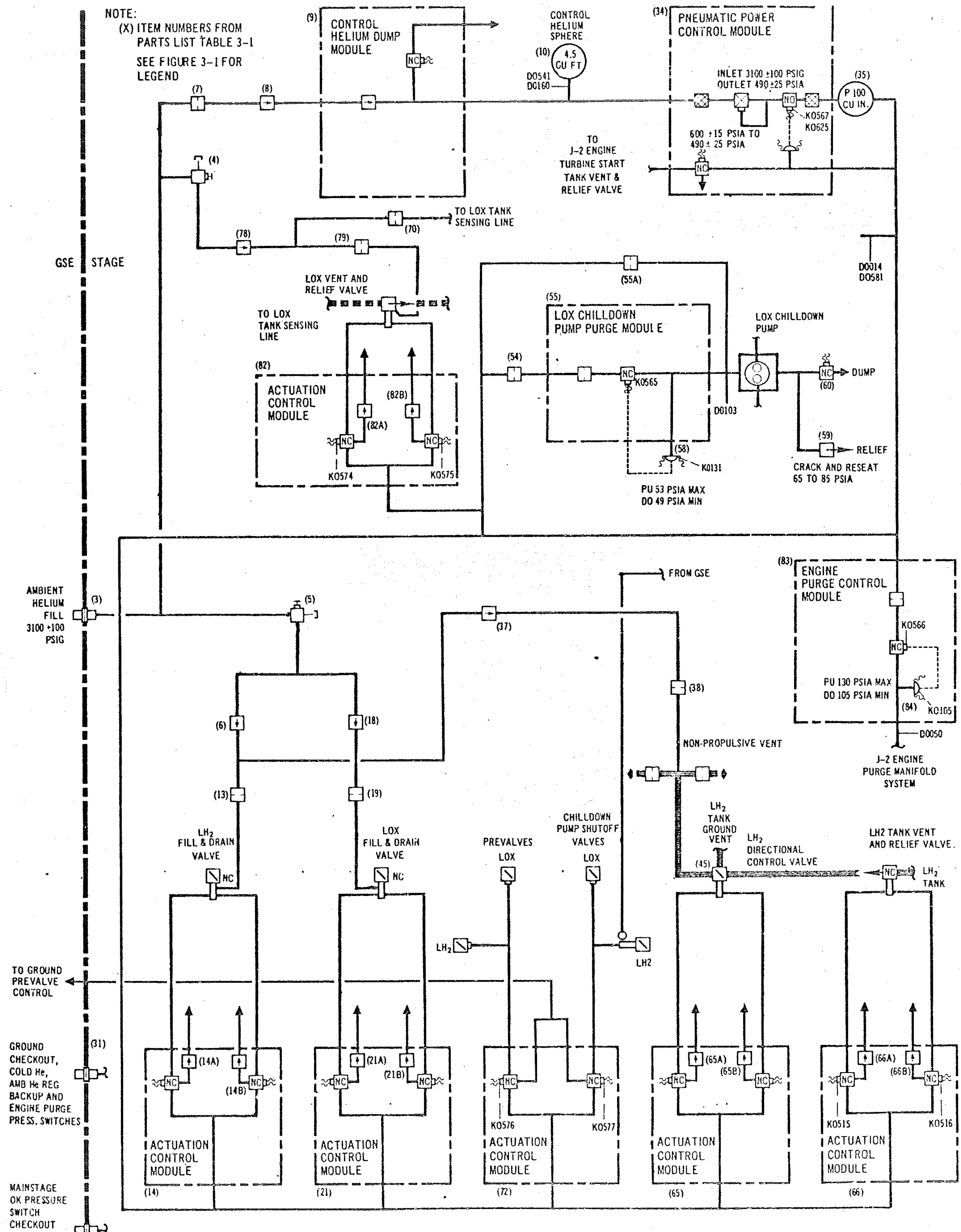

Figure 9-1. Pneumatic Control and Purge System

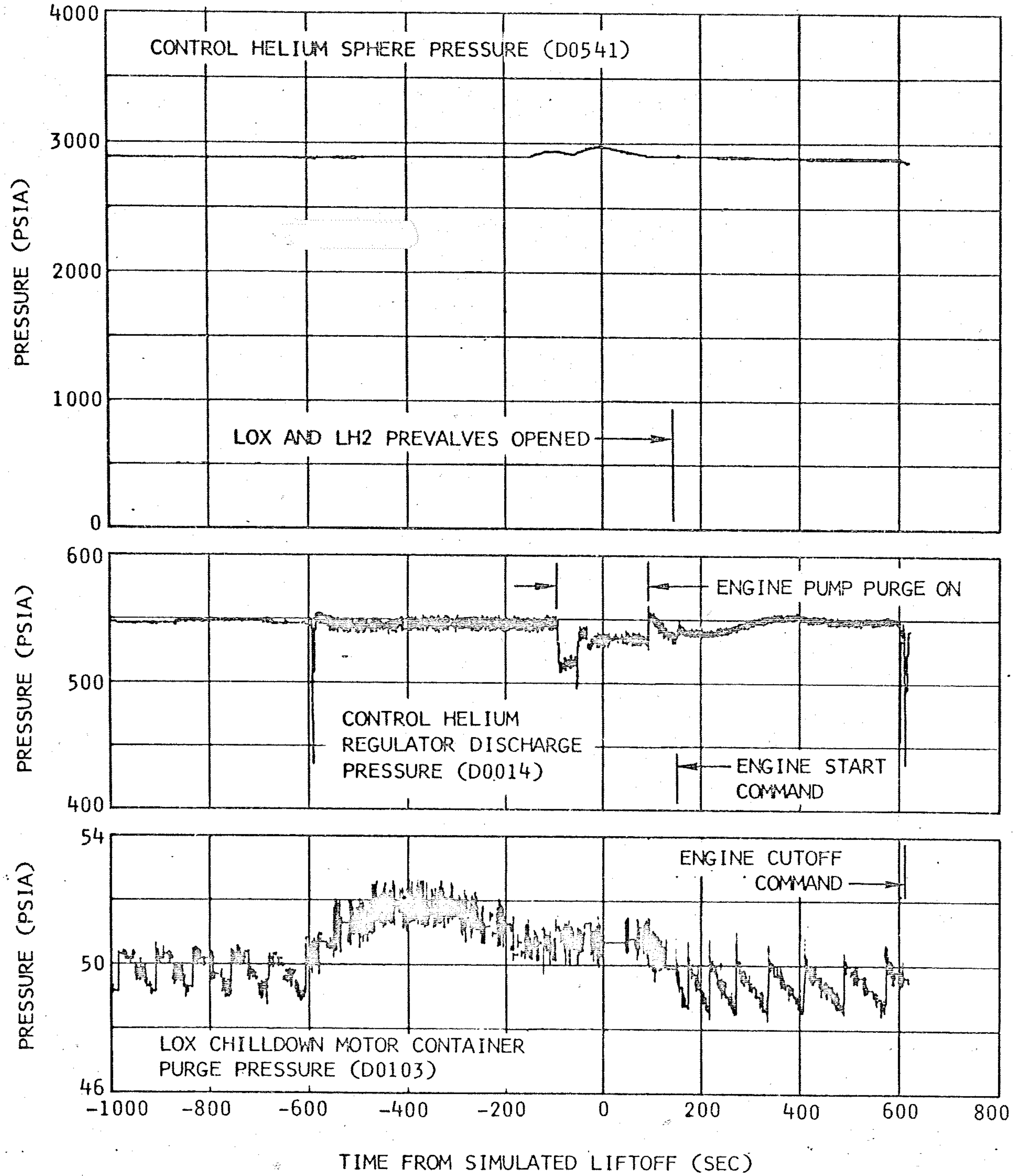

Figure 9-2. Pneumatic Control and Purge System Performance

10

PROPELLANT UTILIZATION SYSTEM

10. PROPELLANT UTILIZATION SYSTEM

The propellant utilization (PU) system performed as expected during the acceptance firing and all test objectives were satisfactorily accomplished. This was the first S-IVB/IB stage to be acceptance fired with the common propellant load of 38,000 lbm LH2 and 193,273 lbm LOX. This was also the first acceptance firing of the reshaped LH2 mass sensor. The final indicated LOX and LH2 masses loaded were 0.49 percent higher and 0.42 lower, respectively, than the actual masses based on the flow integral analysis. The PU system operated in the closed-loop mode throughout the firing with a reference mixture ratio (RMR) of 4.7:1. PU valve cutback occurred at Engine Start Command (ESC) +233 sec as compared to the predicted cutback time of ESC +265 sec. Based on extrapolation from the conditions at cutoff, depletion would have occurred with 215 lbm of usable LH2 on board as compared to a guaranteed maximum flight residual of 575 lbm.

The engine thrust variations were well within the thrust variation limits derived for the CEI specification. No engine performance shifts occurred during RMR control at 4.7:1.0. Use of both reshaped LOX and LH2 sensors significantly reduced sensor-induced thrust variations. The mean thrust slope during the last 70 sec of burn was one lbf/sec and the thrust variation band was ±490 lbf.

The actual PU valve history exhibited a more gradual slope following cutback than the predicted. This slope deviation, which also occurred in the S-IVB-503N acceptance firing data, is indicative of a gain difference between the actual PU system and the simulation model. The actual PU system gain was approximately 3 db lower than the postfiring simulation. Investigation of test data obtained during checkout of the PU electronics assembly for the S-IVB-209 acceptance firing revealed 1.7 db of the difference.

10.1 PU System Calibration

The nominal pre-acceptance mass sensor calibration was determined from previous test results. The propellant masses at the upper and lower calibration point were determined from calculated unique tank volume data and predicted propellant densities. The capacitance at the lower point was determined from vendor's sensor calibration data and fast drain data from previous acceptance firings. The LOX sensor capacitance at the upper calibration point was determined from the S-IVB-209 vendor's air capacitance test and immersed LOX sensor data from the S-IVB-207 stage. The LH2 sensor capacitance at the upper calibration point was determined from the S-IVB-503N immersion test and S-IVB-209 vendor's air capacitance. The LOX and LH2 PU mass sensor calibrations are listed in the following table:

PU Mass Sensor	Cap (pf)	Mass (lbm)	Location
LOX	281.70	1,284	Bottom of Inner Element
	413.05	196,224	Top of Inner Element
LH2	970.18	214	Bottom of Inner Element
	1,186.24	44,777	Top of Inner Element

10.2 Propellant Loading

Propellant loading was accomplished automatically by the loading computer. The following is a tabulation of the desired, indicated, and actual full propellant loads at ESC:

Propellant Load	LOX (lbm)	LH2 (lbm)
Desired full load (predicted)	193,273	38,000
Indicated full load (PU reading)	193,203	38,061
Actual full load (flow integral)	192,260	38,222
Difference (indicated less desired)	-70	61
Difference (actual less desired)	-1,013	222
Difference (indicated less actual)	943	-161

10.3 Propellant Mass History

The flow integral method was used to determine the actual propellant full load and mass history. The results of the flow integral method of mass determination will be used to recalibrate the PU system for flight.

The flow integral method consists of determining the mass flowrates of LOX and LH2 and integrating as a function of time to obtain total consumed mass during firing. Flow integral mass values are based on the analysis of engine flowmeter data, thrust chamber pressure and temperature differentials, engine influence equations, and engine tag values.

The initial full load mass is determined by adding the propellant residuals at engine cutoff, the fuel pressurant added to the ullage and the propellant lost to boiloff, to the total mass consumed. Residual mass values at engine cutoff are based on the best estimate method (paragraph 10.4). The following tabulation presents the propellant mass history for salient times during the acceptance firing:

TIME	FLOW INTEGRAL MASS (lbm)		CORRECTED PU SYSTEM(1) MASS (lbm)		DEVIATION(2) (lbm)	
	LOX	LH2	LOX	LH2	LOX	LH2
Simulated Liftoff (T_0) and Engine Start Command	192,260	38,222	193,188	38,419	928	197
PU Valve Cutback ESC +233 sec	87,262	19,154	87,813	19,131	489	-23
Engine Cutoff Command ESC +458.841 sec	2,311	1,366	2,324	1,391	13	25

NOTES: (1) Total mass in tank as determined by the PU system corrected for nonlinearities.

(2) Deviation of the corrected PU system mass from the flow integral mass.

10.4 Propellant Residuals

Propellant residuals were computed at Engine Cutoff Command using both the PU mass sensor and the residual point level sensors. Two level sensors (L0005 and L0004) in the LOX tank and one level sensor (L0002) in the LH2 tank were activated during the firing and were used for the residual computations.

The residuals derived from the point level sensors were generated using engine consumption data to extrapolate from level sensor activation to engine cutoff. A statistical average residual was computed for the point level sensors for each propellant tank. The final residual masses at engine cutoff are the best estimate residuals generated by weighted averaging the level sensor and PU mass residuals.

The following table presents the propellant residuals determined by the PU mass sensor and the residual point level sensors at engine cutoff:

LEVEL SENSOR (ACTIVATION TIME)	LOX (lbm)			LH2 (lbm)		
	PU SYSTEM VALUE	LEVEL SENSOR	LEVEL SENSOR RESIDUAL (EXTRAPOLATED TO ECC)	PU SYSTEM VALUE	LEVEL SENSOR	LEVEL SENSOR RESIDUAL (EXTRAPOLATED TO ECC)
L0005 (ESC +437.58 sec)	9,930	9,864	2,249			
L0004* (ESC +459.50 sec)	2,220	2,199	2,323			
L0002 (ESC +446.42 sec)				2,253	2,308	1,350
Engine Cutoff (ESC +458.84 sec)	2,324 ±320		2,305** ±226	1,391 ±75		1,350** ±59
Best Estimate Residuals***	2,311 ±185			1,366 ±46		

* Level sensor L0004 activated immediately after engine cutoff. Residual for this sensor was computed by adding the engine propellant consumption during the cutoff transient to the level sensor computed mass.

** Statistical average of level sensor residuals.

*** Statistically weighted average of level sensor and PU system residuals.

10.5 PU System Response

The tank-to-sensor mismatch for the LOX and LH2 mass sensor normalized to the sensor end points are presented in figures 10-1 and 10-2. Mismatch values are presented including and excluding manufacturing nonlinearities for comparison. The maximum LOX mass sensor error was 475 lbm at

52,000 lbm total LOX load or approximately 0.25 percent error at the 27 percent level of the tank. The maximum LH2 mass sensor error was +80 lbm at the 14,000 lbm level and -80 lbm at the 27,000 lbm level of total LH2 load or approximately 0.19 percent error at the 32 and 63 percent levels of the tank, respectively.

PU system valve cutback occurred at ESC +233 sec, 32 sec earlier than the predicted cutback time of ESC +265 sec (figure 10-3). The PU valve position trace exhibited a more gradual slope following cutback than predicted and reached a steady-state position with a mean value approximately 2.5 deg lower than predicted. The difference between the actual and predicted PU valve response following cutback was caused mainly by a PU system calibration deviation and by PU system gain deviation. The following table summarizes the deviations between the actual and predicted PU valve position histories and their sources.

Description	Cutback Time Deviation (sec)	Valve Position Shift (deg)
Loading computer deviations	-5.5	0
Mass/capacitance calibration deviations	-14.5	-3.3
Difference between predicted and actual tank-to-sensor mismatch nonlinearities	+3.0	-1.7
PU system gain deviation -3 db	-10	+1.0
Total	-27.0	-4.0

Considering the above factors, the predicted cutback time would decrease by 27 sec and the mean level of valve position after the cutback transient would be decreased by 4.0 deg. This provides satisfactory agreement between the actual valve response and the postfiring reconstruction as shown in figure 10-4.

10.5.1 Loading Computer Deviations

Loading computer deviations are the difference between the PU system indicated loads at ESC and the desired PU system indicated loads at ESC.

The loading deviations were -70 lbm LOX (-0.036 percent) and +61 lbm LH2 (0.016 percent). The combined effect of these loading computer deviations decreased cutback time by 5.5 sec. The mean level of the valve position after cutback is not affected by these loading computer deviations.

10.5.2 Mass/Capacitance Calibration Deviations

Calibration deviations at ESC were +0.490 percent LOX and -0.421 percent LH2 thus causing the initial LOX mass to be under-loaded and the initial LH2 mass to be over-loaded by the above percentages. Calibration deviations at ECC were -0.078 percent LOX and -0.097 percent LH2. The slope deviations between ESC and ECC were +0.568 percent LOX and -0.324 percent LH2. The desired reference mixture ratio (RMR) for the S-IVB-209 acceptance firing was 4.7:1.0. The bridge-gain-ratio (BGR) was therefore calibrated at 4.7:1.0. Since PU sensor calibration deviations also affect the BGR, the actual ratio was 4.65:1.0. The calibration deviations decreased cutback time by 14.5 sec and shifted the mean value of valve position by -3.3 deg.

The total loading deviations including calibration and loading computer deviations were -0.53 percent LOX and -0.581 percent LH2.

10.5.3 Difference Between Predicted and Actual Tank-to-Sensor Mismatch

The effect of the differences between the average of previous acceptance firing flow integral tank-to-sensor mismatch results used for the S-IVB-209 stage prediction and the actual flow integral tank-to-sensor mismatch increased cutback time by 3 sec and shifted the mean valve position by 1.7 deg.

Figures 10-1 and 10-2 present the predicted and actual LOX and LH2 mismatch curves normalized to the sensor extremities. Actual mismatch values are plotted including and excluding sensor manufacturing nonlinearities. Two predictions are provided, one is for the measured tank-to-sensor mismatch based on internal tank measurements including manufacturing nonlinearities and the other is an average of previous test data excluding manufacturing nonlinearities. The actual mismatch curves are based on the combined flow integral computer program.

10.5.4 PU System Gain Difference

The postfiring reconstruction of the PU valve history was obtained from actual acceptance firing data and is compared to the actual valve profile in figure 10-3. This resulted in a reasonably close comparison between actual and reconstructed data; however, the actual cutback occurred 15 sec earlier, the PU valve cutback response was slower, and the mean valve position was shifted -2.0 deg. The lag between valve cutback and thrust cutback was also larger then predicted (22 sec vs 16 sec). This time lag was caused by the increased time experienced for the PU valve to travel through the nonlinearity gain phase (+32 to +15 deg). During cutback, thrust cutback is normally observed at a valve position of approximately +15 deg. The above factors indicate that the S-IVB-209 stage PU system gain was lower than the PU system simulated gain. The PU system simulation gain reduction required to reconstruct the actual valve cutback transient was 3 db. A reconstruction with the gain reduction is compared to the actual in figure 10-4. This gain difference accounts for the decreased slope of the valve cutback profile, the increased lag between valve and thrust cutback, 10 sec of the early cutback, and a mean valve position shift of +1.0 deg.

Investigation of test data obtained during checkout of the PU electronics assembly for the S-IVB-209 acceptance firing has isolated 1.7 db of the difference. Other possible sources of gain reduction are presently being investigated and the flight PU model for S-IVB-209 will reflect the results of this study.

10.5.5 PU Efficiency

The closed-loop PU efficiency is determined by expressing the usable residual propellant at depletion cutoff as a percentage of the total propellant load. LOX depletion cutoff would have occurred 5.148 sec after the actual ECC. Total stage propellant consumption rates at ECC were 353.89 lbm/sec for LOX and 74.966 lbm/sec for LH2. Extrapolating these flowrates to the theoretical depletion cutoff results in a usable LH2 residual of 215 lbm and a PU efficiency of 99.907.

10.5.6 Thrust Variations

The thrust variations after cutback were reduced due to the reshaping of the LH2 propellant sensor. This was the first test of the reshaped LH2 propellant sensor combined with the previously acceptance fired reshaped LOX sensor. The complete thrust profile is presented in figure 6-12 and figure 6-16 shows expanded thrust plots of the three significant phases of flight defined for the Contract End Item (CEI) Specification. A tabulation of the actual thrust variations compared to the CEI Specification limits for flight are presented in table 6-6.

The thrust variations after cutback were within the CEI thrust limits recently established for the S-IVB-209 CEI Specification. The thrust cutback transient was slower than predicted due to the lower PU system gain (paragraph 10.5.4). The mean slope during the last 70 sec of burn was 1 lbf/sec and the maximum thrust variations about the mean slope was ±490 lbf. The maximum rate during this period was 87 lbf/sec.

There was a thrust tailup of 1,000 lbf during the last 15 sec of burn corresponding to a PU valve tailup of 1.5 deg. The S-IVB-209 stage employing the reshaped LH2 mass sensor exhibited a significant reduction in thrust tailup from the values experienced on previous stages.

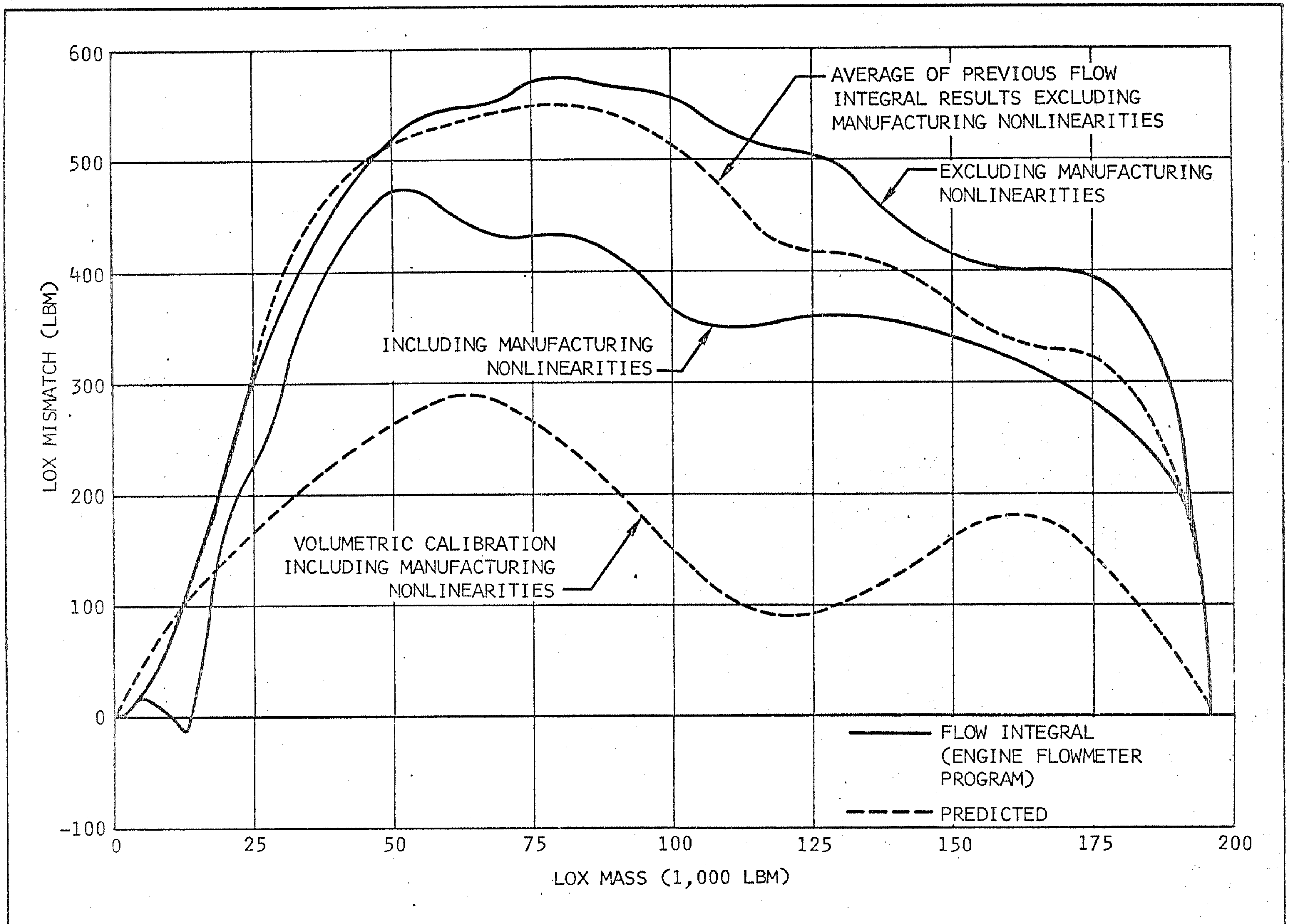

Figure 10-1. LOX Tank-to-Sensor Mismatch Normalized to Sensor End Points

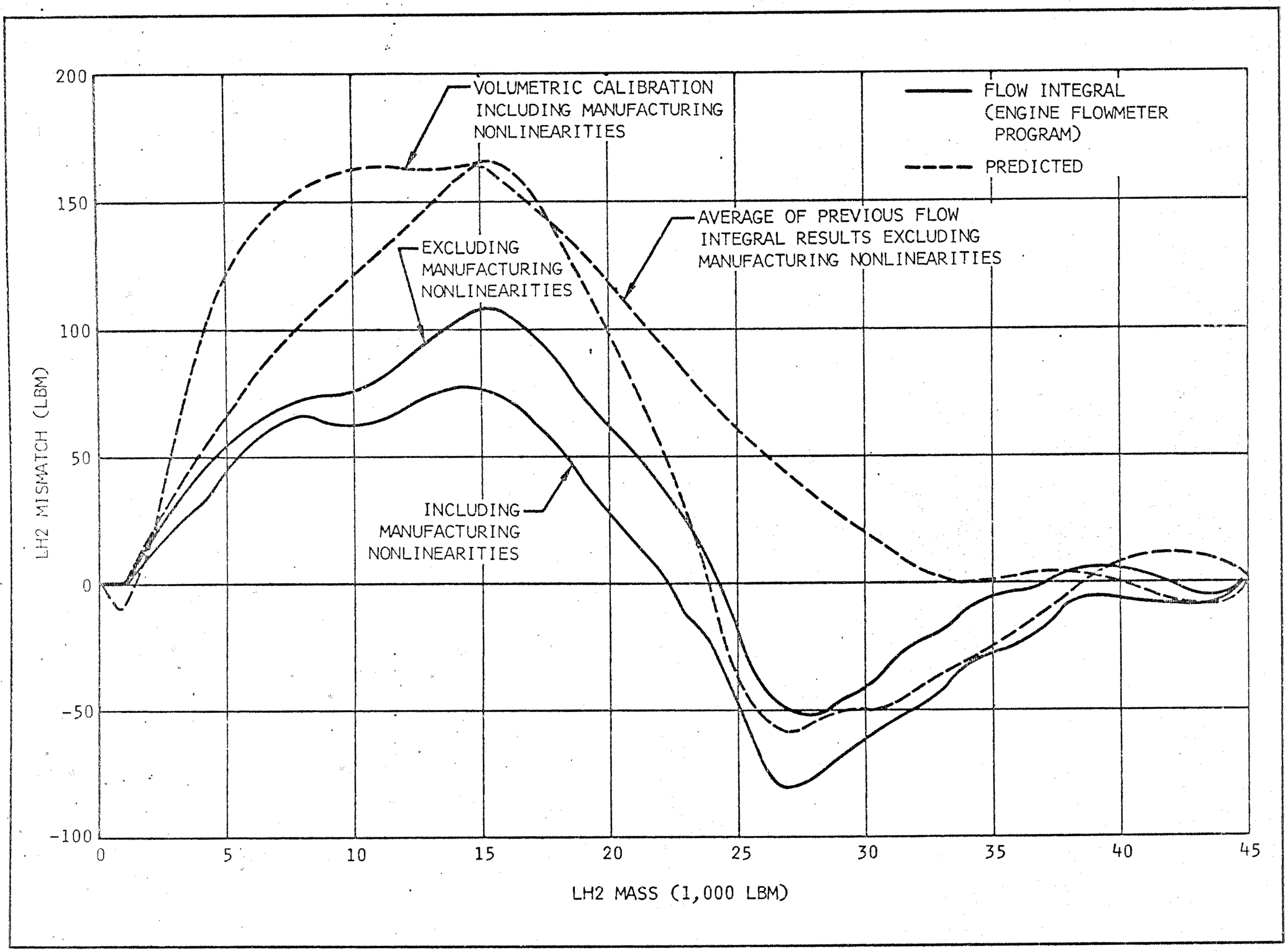

Figure 10-2. LH2 Tank-to-Sensor Mismatch Normalized to Sensor End Points

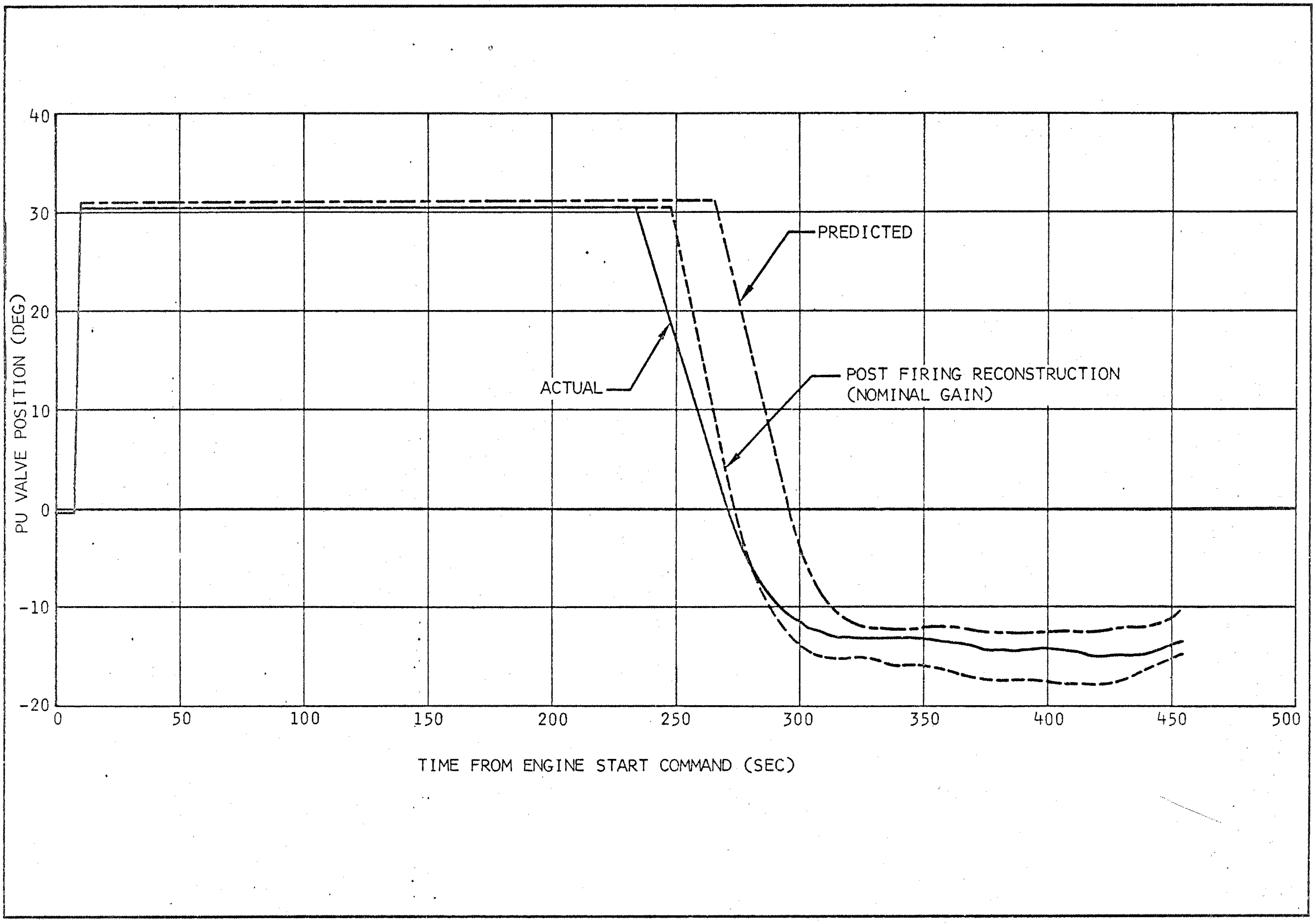

Figure 10-3. PU Valve Position

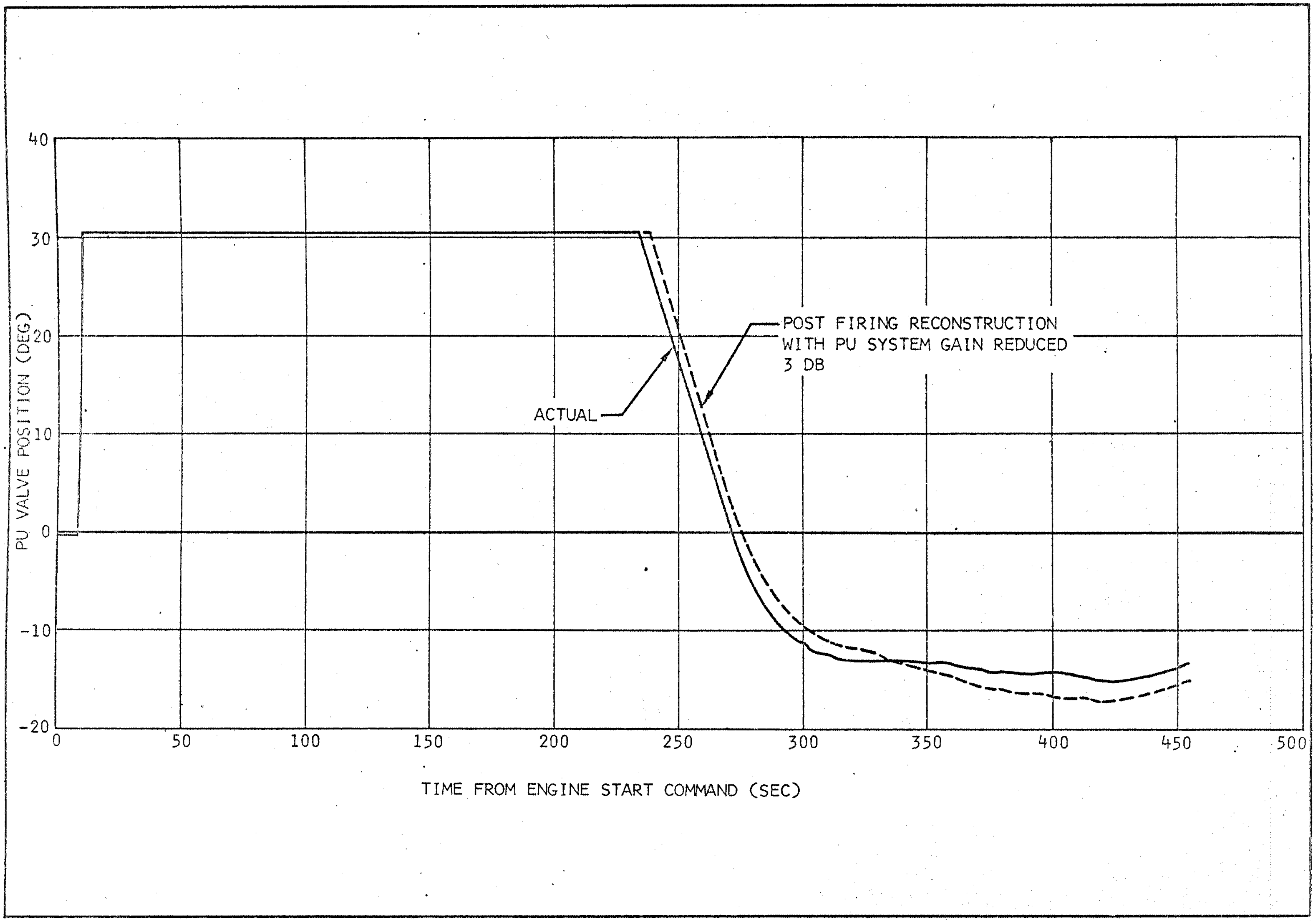

Figure 10-4. PU Valve Position Reconstruction with PU System Gain Reduction

DATA ACQUISITION
SYSTEM

11. DATA ACQUISITION SYSTEM

The data acquisition system performed as designed by demonstrating the competency of acquiring stage information, conditioning the data signals, translating these signals into proper telemetry format, and transmitting the telemetry information to a ground station. The measurements which comprise this system are specified in Douglas Drawing No. 1B43562S, *Instrumentation Program and Components List (IP&CL)*. A measurement summary is presented in the following table:

Measurement efficiency	98.86%
Total number of measurements designed	232
Total number of measurements deleted	57
Total number of active measurements	157
Measurement failures	2
Total successful measurements	173

The data acquisition system satisfactorily accomplished its acceptance firing criterion as specified by the *S-IVB-209 Stage Acceptance Firing Test Plan* (DAC 47459A, as amended). The system performed as expected; no system malfunction was observed and the system was free of radio frequency interference and was electromagnetically compatible with other stage systems.

11.1 Instrumentation System Performance

The instrumentation system performance was excellent during the acceptance firing with the exception of two (2) pressure measurement discrepancies. The system performance is tabulated in table 11-1; status of the inactive measurements is shown in table 11-2.

Two measurements failed to exhibit valid data (table 11-3): D0050 - Engine Pump Purge Regulator Pressure data were invalid at T_0 +604 sec and at T_0 +612 sec; D0054 - Fuel Tank Inlet Pressure was known to have a bad transducer before the firing. No replacement was made.

Measurements D0183 and D0184, LH2 Tank Non-Prop Vent 1 and 2, are known RFI susceptible parameters and gave trend data only.

An evaluation of acceptance firing data revealed that M0069, T/M Aft 5 Volt reference exhibited approximately 2 to 4 percent interference amplitude during chilldown inverter operation. The interference amplitude is not existent on this measurement during the time the 5 volt references will be used for inflight calibrations.

11.2 Telemetry System Performance

The telemetry system performance was good. There was no loss of system synchronization and good data were received from all channels. DDAS hardware (600 kc) to DDAS open-loop (RF) comparison did not reveal any data discrepancies (table 11-4).

Inflight T/M calibration was observed at T_0 -3,569, T_0 +92, and T_0 +1,298 sec. The T/M calibration during the operation of the chilldown inverters at T_0 +31 sec indicated data point dispersions of ± 10 bits with periodic dropouts of 16 bits; however, the T/M calibration, observed when the chilldown inverters were off at T_0 +1,298 sec, showed maximum data point dispersions of only ± 5 bits, which is well within the required tolerance.

11.3 RF System Performance

No difficulties were encountered in the performance of the RF system. The RF power output after correcting for signal conditioning anomaly was 19.5 W. The correction is to compensate for the 115 ohm series resistor on the output of the voltage generator which is used to calibrate the low gain amplifier following the power detector. The VSWR was calculated to be 1.43:1. RF system performance data are presented in the following table:

RF Power Amplifier Output (minimum acceptable is 12 W)	19.5 W
Deviation	32 kc
Ground Station Signal Strength (UV)	10 k
Reflected Power	0.6 W
VSWR (maximum acceptable is 1.8:1)	1.43:1

11.4 Electromagnetic Compatibility

The data acquisition system did not interfere with other stage systems in the areas of electromagnetic compatibility; however, the strain gage pressure transducer for measurements D0183-409 and D0184-409 exhibited RFI susceptibility giving trend data only and measurement M0069-404 showed noise during chilldown inverter operation. This interference will not exist during the time the 5 V reference will be used for inflight calibrations.

11.5 Emergency Detection System Measurements

The LH2 and LOX tank ullage emergency detection system (EDS) pressure measurements performed satisfactorily. The variation between the LOX EDS measurements, which is within instrumentation tolerance, was introduced in the data reduction process.

11.6 Hardwire Data Acquisition System Performance

The ground instrumentation system (GIS) provides a backup and data comparison for certain stage telemetry system parameters in addition to recording measurements from the ground support and facility equipment. The GIS also provides strip charts for redline and cutoff parameter monitoring. The GIS performance during the acceptance firing was satisfactory.

The following table presents the type of recording equipment and the number of channels used during the acceptance firing.

Ground Recorder	Channels Assigned
Beckman 210 Digital Data System	152
Constant Bandwidth FM	67
Wideband FM	7
Strip Charts	37
Total	263

Table 11-5 presents a list of the various types of measurement data recorded and the performance of the system.

11.6.1 Hardwire Measurement Discrepancies

There were three measurement failures, yielding an overall hardwire measurement efficiency of 98.25 percent. The following measurements were classified as failures:

Measurement No.	Parameter	Remarks
D0516	Press LH2 Pump Discharge Press	Ambient shifted. Transducer was replaced.
D0521	Press LOX Pump Primary Seal Cavity	5 to 7 percent ambient high; pin in signal conditioning unit pushed out. Connection was repaired postfire.
F0507	Flow Eng LH2 AC Output	Off scale high. Static test uncovered no problems - dual element pickup. F-2 - T/M measurement was OK.

TABLE 11-1
INSTRUMENTATION SYSTEM PERFORMANCE SUMMARY

FUNCTION	NUMBER ASSIGNED PER IP&CL	DELETED	INACTIVE	ACTIVE	FAILED
Temperature	45	11	3	31	0
Pressure	58	22	2	34	0
Flow	4	0	0	4	0
Position	8	0	0	8	0
Events	68	5	9	54	2
Liquid Level	5	1	0	4	0
Volt, Current, Freq.	29	0	0	29	0
Miscellaneous	13	4	0	9	0
Speed	2	0	0	2	0
Totals	232	43	14	175	2

TABLE 11-2 (Sheet 1 of 3)
INACTIVE MEASUREMENTS

MEASUREMENT NO.	PARAMETER	REMARKS
C0007-401	Temp - Engine Control Helium	Open - Hardwire reqm't - T/M disconnected
C0050-401	Temp - Hydr Pump Inlet Oil	Open - Hardwire reqm't - T/M disconnected
C0102-411	Temp - Fwd Battery 1	*Simulated - Primary battery not installed
C0103-411	Temp - Fwd Battery 2	*Simulated - Primary battery not installed
C0104-404	Temp - Aft Battery 1	*Simulated - Primary battery not installed
C0105-404	Temp - Aft Battery 2	*Simulated - Primary battery not installed
C0166-414	Temp - He Sphere Gas, Mod 1 (APS)	Simulated - APS not installed
C0167-415	Temp - He Sphere Gas, Mod 2 (APS)	Simulated - APS not installed
C0168-414	Temp - Oxid Tank Outlet, Mod 1 (APS)	Simulated - APS not installed
C0169-415	Temp - Oxid Tank Outlet, Mod 2 (APS)	Simulated - APS not installed
C0170-414	Temp - Fuel Tank Outlet, Mod 1 (APS)	Simulated - APS not installed
C0171-415	Temp - Fuel Tank Outlet, Mod 2 (APS)	Simulated - APS not installed
C0200-401	Temp - Fuel Injection	Open - Hardwire reqm't - T/M disconnected
C0211-411	Temp - Fwd Batt No. 1 Unit No. 2	*Simulated - Primary battery not installed
D0041-403	Press - Hydraulic System	No data - Hardwire reqm't - T/M disconnected
D0042-403	Press - Reservoir Oil	No data - Hardwire reqm't - T/M disconnected
D0063-414	Press - Fuel Sply Man, Mod 1 (APS)	Simulated - APS not installed
D0064-414	Press - He Reg Inlet, Mod 1 (APS)	Simulated - APS not installed
D0065-414	Press - He Reg Outlet, Mod 1 (APS)	Simulated - APS not installed
D0066-415	Press - Oxid Sply Man, Mod 2 (APS)	Simulated - APS not installed
D0067-415	Press - Fuel Sply Man, Mod 2 (APS)	Simulated - APS not installed

* Battery simulator heaters have been deleted; therefore, only Battery SIM Ambient was recorded.

TABLE 11-2 (Sheet 2 of 3)
INACTIVE MEASUREMENTS

MEASUREMENT NO.	PARAMETER	REMARKS
D0068-415	Press - He Reg Inlet, Mod 2 (APS)	Simulated - APS not installed
D0069-415	Press - He Reg Outlet, Mod 2	Simulated - APS not installed
D0078-414	Press - Attitude Contr Chamber, 1-1	Simulated - APS not installed
D0079-414	Press - Attitude Contr Chamber, 1-2	Simulated - APS not installed
D0080-414	Press - Attitude Contr Chamber, 1-3	Simulated - APS not installed
D0081-415	Press - Attitude Contr Chamber, 2-1	Simulated - APS not installed
D0082-415	Press - Attitude Contr Chamber, 2-2	Simulated - APS not installed
D0083-414	Press - Attitude Contr Chamber, 2-3	Simulated - APS not installed
D0084-414	Press - Oxid Sply Man, Mod 1 (APS)	Simulated - APS not installed
D0089-414	Press - Fuel Tank Ullage, Mod 1 (APS)	Simulated - APS not installed
D0090-415	Press - Oxid Tank Ullage, Mod 2 (APS)	Simulated - APS not installed
D0091-415	Press - Fuel Tank Ullage, Mod 2 (APS)	Simulated - APS not installed
D0092-415	Press - Oxid Tank Ullage, Mod 2 (APS)	Simulated - APS not installed
D0093-414	Press - Fuel Tank Outlet, Mod 1 (APS)	Simulated - APS not installed
D0094-414	Press - Oxid Tank Outlet, Mod 1 (APS)	Simulated - APS not installed
D0095-415	Press - Oxid Tank Outlet, Mod 2 (APS)	Simulated - APS not installed
D0096-415	Press - Fuel Tank Outlet, Mod 2 (APS)	Simulated - APS not installed
G0003-401	Posit - Main LOX Valve	Simulated - Hardwire reqm't
G0004-401	Posit - Main LH2 Valve	Simulated - Hardwire reqm't
G0005-401	Posit - Gas Generator Valve	Simulated - Hardwire reqm't
G0008-401	Posit - LOX Turbine Bypass Valve	Simulated - Hardwire reqm't
G0009-401	Posit - GH2 Start Tank Valve	Simulated - Hardwire reqm't

TABLE 11-2 (Sheet 3 of 3)
INACTIVE MEASUREMENTS

MEASUREMENT NO.	PARAMETER	REMARKS
K0020-401	Event - ASI LOX Valves, OPEN	No data - Computer reqm't
K0095-401	Event - T/C LH2 Inj Temp OK	No data - J-2 Engine Modification
K0116-401	Event - Gas Gen Valve, CLOSED	No data - Computer reqm't
K0119-401	Event - Main LH2 Valve, CLOSED	No data - Computer reqm't
K0121-401	Event - Main LOX Valve, CLOSED	No data - Computer reqm't
K0123-401	Event - Start Tank Disch Valve, CLOSED	No data - Computer reqm't
K0126-401	Event - LOX Bleed Valve, CLOSED	No data - Computer reqm't
K0127-401	Event - LH2 Bleed Valve, CLOSED	No data - Computer reqm't
K0128-404	Event - Switch Selector	No data - Computer reqm't
L0007-403	Level - Reservoir Oil	Simulated - Hardwire reqm't
N0037-414	Misc - Qty Oxid Tank, Mod 1 (APS)	Simulated - APS not installed
N0038-415	Misc - Qty Oxid Tank, Mod 2 (APS)	Simulated - APS not installed
N0039-414	Misc - Qty Oxid Tank, Mod 1 (APS)	Simulated - APS not installed
N0040-415	Misc - Qty Fuel Tank, Mod 1 (APS)	Simulated - APS not installed

TABLE 11-3
MEASUREMENT DISCREPANCIES

MEASUREMENT NO.	PARAMETER	REMARKS
D0054-410	Press - Fuel Tank Inlet	This transducer malfunctioned prior to static firing. Dispositioned to remove and replace during postfiring checkout. The RAC Cals read -0.123vdc and the ambient value read 104 psia, which is full scale. The transducer has been rejected per FARR A251588 (V) and A251589 (Detail).
D0050-403	Press - Eng Pump Purge Regulator	Data became erratic at T_0 +604 sec and at T_0 +612 sec data read -9.0 psia off scale low. Postfiring checkout determined the transducer wiper was open circuited. The transducer has been rejected per FARR A255206.

TABLE 11-4 (Sheet 1 of 2)
TELEMETRY TO HARDWIRE DATA COMPARISON (T_0 +213 SEC)

PARAMETER	TELEMETRY			HARDWIRE				
	UNITS	MEAS NO.	PCM	UNITS	MEAS NO.	GIS	S/C	F/M
Temp - Fuel Turbine Inlet	°R	C0001	1,704	°R	C0755	1,658	--	1,692
Temp - LH2 Pump Inlet	°R	C0003	37.7	°R	C0658	37.6	37.5	37.8
Temp - LOX Pump Inlet	°R	C0004	164.1	°R	C0659	163.9	164.4	164.0
Temp - GN2 Start Bottle	°R	C0006	221	°R	C0649	231	240	--
Temp - Elect Control Assy.	°R	C0011	530	°R	C0657	528	--	--
Temp - LOX Tank He Inlet	°R	C0016	496	°R	C0662	492	--	--
Temp - LOX Pump Discharge	°R	C0133	169.8	°R	C0648	169.6	--	169.8
Temp - LH2 Pump Discharge	°R	C0134	52.4	°R	C0644	52.3	52.6	--
Temp - Thrust Chamb Jacket	°R	C0199	135	°R	C0645	141	129	--
Temp - Cold He Sphere No. 4	°R	C0210	36	°R	C0661	36.1	34.1	--
Press - Thrust Chamber	psia	D0001	789	psig	D0524	774	780	--
Press - LH2 Pump Inlet	psia	D0002	27.6	psig	D0536	15	15.0	12
Press - LOX Pump Inlet	psia	D0003	40.7	psig	D0537	25	28	--
Press - Main LH2 Injector	psia	D0004	882	psig	D0518	822	--	875
Press - LH2 Pump Discharge	psia	D0008	1,229	psig	D0516	1,336	--	1,350
Press - LOX Pump Discharge	psia	D0009	1,060	psig	D0522	1,103	--	1,080
Press - GG Chamber	psia	D0010	719	psig	D0530	709	--	680
Press - Cont He Reg Discharge	psia	D0014	538	psig	D0581	537	536	545
Press - Cold He Sphere	psia	D0016	2,104	psig	D0542	2,049	2,100	--
Press - GH2 Start Bottle	psia	D0017	298	psig	D0525	286	300	290
Press - Eng Reg Outlet	psia	D0018	411	psig	D0535	395	394	--
Press - Cont He Supply	psia	D0019	2,486	psig	D0534	2,479	2,502	--

TABLE 11-4 (Sheet 2 of 2)
TELEMETRY TO HARDWIRE DATA COMPARISON (T_0 +213 SEC)

PARAMETER	TELEMETRY			HARDWIRE				
	UNITS	MEAS NO.	PCM	UNITS	MEAS NO.	GIS	S/C	F/M
Press - He Amb Sphere	psia	D0160	2,899	psig	D0541	2,904	2,905	--
Press - LOX Tank U11 EDS-1	psia	D0177	29.7	psig	D0539	15.1	15.5	--
Press - LOX Tank U11 EDS-2	psia	D0178	29.4	psig	D0539	15.1	15.5	--
Press - LH2 Tank U11 EDS-1	psia	D0179	37.7	psig	D0540	23.5	23.5	--
Press - LH2 Tank U11 EDS-2	psia	D0180	37.6	psig	D0540	23.5	23.5	--
Press - Common Blkhd	psia	D0237	-0.2	psia	D0545	0.1	0.1	--
Flowrate LOX	gpm	F0001	2,907	gpm	F0506	2,902	--	2,917
Flowrate LH2	gpm	F0002	8,017	gpm	F0507	9,186	--	7,978
Position - Pitch Act	deg	G0001	-0.1	deg	G0504	-0.1	0.0	-0.1
Position - Yaw Act	deg	G0002	0.0	deg	G0505	-0.1	0.07	-0.1
Voltage - Eng Control Bus	vdc	M0006	28.5	vdc	M0514	28.4	28.4	29
Voltage - Eng Ignition Bus	vdc	M0007	28.8	vdc	M0515	28.6	28.7	29
Voltage - Aft Battery - 1	vdc	M0014	28.7	vdc	M0541	28.7	--	29
Voltage - Aft Battery - 2	vdc	M0015	59.3	vdc	M0540	59.1	58.9	59.5
Voltage - Fwd Battery - 1	vdc	M0016	28.1	vdc	M0543	28.5	--	28.0
Voltage - Fwd Battery - 2	vdc	M0018	26.7	vdc	M0542	27.0	--	27.2
Current - Fwd Battery - 1	amp	M0019	11	amp	M0536	11.6	11.8	11.5
Current - Fwd Battery - 2	amp	M0020	5.1	amp	M0537	4.3	4.9	5.0
Current - Aft Battery - 1	amp	M0021	10	amp	M0534	11.5	11.25	11.5
Current - Aft Battery - 2	amp	M0022	20	amp	M0535	21	21	22.5
Speed - LOX Pump	rpm	T0001	8,565	rpm	T0502	8,682	--	8,688
Speed - LH2 Pump	rpm	T0002	27,260	rpm	T0503	27,458	--	27,408
Position - PU Valve	deg	G0010	30.5	deg	G0503	30.5	32.8	32.5

TABLE 11-5
HARDWIRE DATA ACQUISITION SYSTEM

MEASUREMENT TYPE	RECORDED	FAILED	PARTIALLY SUCCESSFUL	SUCCESSFUL (PERCENT)
Pressure	86	2	0	97.7
Temperature	41	0	0	100
Flow	2	1	0	50.0
Position	10	0	0	100
Voltage/Current	33	0	0	100
Events/Switches	97	0	0	100
Speed	2	0	0	100
Level	3	0	0	100
Vibration	12	0	0	100
Miscellaneous	0	0	0	100
Totals	286	3	0	98.25

12

ELECTRICAL POWER AND CONTROL SYSTEMS

12. ELECTRICAL POWER AND CONTROL SYSTEMS

12.1 Electrical Control System

The electrical control system performed satisfactorily as verified in the sequence of events (section 5). All incremental response times to switch selector commands were within the design tolerances.

12.1.1 J-2 Engine Control System

All event measurements verified that the engine control system had responded properly to the engine start and cutoff commands. The Engine Start Command was given by the switch selector 151.844 sec after simulated liftoff. Engine cutoff was initiated at 610.862 sec. Total engine burn time was 459.018 sec.

The ignition detection signal was intermittent during engine burn and was due to flame pattern and probe location. The engine cutoff signal was non-programmed. The main LOX and LH2 valves closed at 0.200 and 0.310 sec respectively after engine cutoff. The LOX and LH2 prevalves closed 1.934 and 1.739 sec respectively after engine cutoff, as verified by the digital events recorder.

12.1.2 Secure Range Safety Command System

The secure range safety command system was tested during the engine burn phase to verify the capability of engine cutoff and propellant dispersion. Evaluation of the data showed that the arm and engine cutoff and propellant dispersion commands were received and that the EBW firing units discharged into their respective pulse sensors. The following measurements were evaluated:

Measurement No.	Parameter
M0030	R/S EBW Firing Unit No. 1
M0031	R/S EBW Firing Unit No. 2
K0141	EBW No. 1 Pulse Sensor Indication
K0142	EBW No. 2 Pulse Sensor Indication
*(K0659)	R/S No. 2 Arm and Engine Cutoff Indication
(K0660)	R/S No. 1 Arm and Engine Cutoff Indication

* Hardwire measurements are in parenthesis.

Measurement No.	Parameter
*(K0692)	R/S No. 2 EBW Arm and Engine Cutoff Indication
(K0693)	R/S No. 1 EBW Arm and Engine Cutoff Indication
N0057	R/S No. 1 Low Level Signal Strength
N0062	R/S No. 2 Low Level Signal Strength

The secure range safety commands, receipt of signals and firing unit performance are shown in figure 12-1.

12.1.3 Control Pressure Switches

A review of the event and pressure measurements verified that each control item functioned properly. Each pressure switch and its associated measurements were evaluated. Listed below are those measurements and a description of their performance.

K0105 Engine Pump Purge Control Regulator Backup Pressure Switch - De-energized
(K0566) Engine Pump Purge Control Module Solenoid Valve - Energized
K0050 Engine Pump Purge Regulator Pressure

The Engine Pump Purge Control Valve Enable ON and OFF Commands were given prior to engine start. The purge orifice size and low back pressure resulted in a purge pressure buildup of 96 pisa which was below the actuation of the pressure switch (105 - 130 psia).

K0131 LOX Chilldown Pump Purge Pressure Switch - De-energized
D0103 He Pressure to LOX Pump Motor Control
(K0565) LOX Chilldown Pump Purge Control Valve - Energized

The LOX chilldown pump helium purge regulator backup pressure switch controlled the LOX pump purge control valve during the LOX Chilldown Purge Control Valve Command to maintain a regulated 49 to 53 psia purge pressure.

K0156 LOX Tank Regulator Backup Press Switch - Energized
(K0571) Cold Helium Shutoff Valves - Energized
D0225 Cold Helium Control Inlet Pressure

* Hardwire measurements are in parenthesis.

The measurements indicated that the cold helium regulator backup pressure switch was de-energized during the test and that the actuation pressure of 465 psia was never attained.

D0177, D0178 Fuel Tank Ullage EDS 1 and 2 Pressures

The LH2 tank flight control pressure switch enabled the LH2 pressurization control module to maintain a 26.5 - 29.5 psia pressure in the LH2 tank during the period that the LH2 Tank Pressure Control Switch Enable Command was on. The ullage pressure never dropped below 26.5 psia as verified by measurements D0177 and D0178. At engine start, the pressure was 30.4 psia.

K0102 LOX Prepress Flight Switch - Energized
D0179, D0180 LOX Tank Ullage EDS 1 and 2 Pressures

The LOX prepressurization flight control pressure switch controlled the heat exchanger bypass valve during the LOX Tank Flight Pressurization Command to maintain 37 to 40.8 psia regulated pressure in the LOX tank.

12.1.4 Vent Valves

The LOX and LH2 vent valves are commanded OPEN and CLOSE by GSE, bypassing the switch selector. The vent valves responded to these commands and operated properly. The GSE commands and their corresponding measurements are listed below:

*(K0576) Fuel Tank Vent Valve Open - Energized
K0001 (K0532) Fuel Tank Vent Valve Closed
K0017 (K0542) Fuel Tank Vent Valve Open

(K0575) Oxidizer Tank Vent Valve Open - Energized
K0002 (K0533) Oxidizer Tank Vent Valve Closed
K0016 (K0543) Oxidizer Tank Vent Valve Open

K0113 LH2 Tank Directional Vent Valve C - Closed
K0114 LH2 Tank Directional Vent Valve D - Closed
(K0561) LH2 Tank Directional Vent Valve - Ground Position
(K0562) LH2 Tank Directional Vent Valve - In-flight Position

* Hardwire measurements are in parenthesis.

12.1.5 Childown Shutoff Valves

These valves were not operated during the acceptance firing.

12.1.6 Fill and Drain Valves (LH2 and LOX)

The fill and drain valves were commanded CLOSED through the umbilical prior to simulated liftoff, and remained closed through the acceptance firing. A review of the following measurements verified that the valves performed satisfactorily:

K0003 *(K0554) Fuel Fill and Drain Valve Closed
K0004 (K0553) LOX Fill and Drain Valve Closed

12.1.7 Depletion Sensors

(K0597) LH2 Depletion Sensor No. 1 - Wet
(K0598) LH2 Depletion Sensor No. 2 - Wet
(K0599) LH2 Depletion Sensor No. 3 - Wet
(K0676) LH2 Depletion Sensor No. 4 - Wet

(K0601) LOX Depletion Sensor No. 1 - Wet
(K0602) LOX Depletion Sensor No. 2 - Wet
(K0603) LOX Depletion Sensor No. 3 - Wet
(K0604) LOX Depletion Sensor No. 4 - Wet

The measurements indicated that all depletion sensors performed as expected during the acceptance firing and no malfunctions were observed. During LH2 loading, LH2 sensor No. 1 indicated dry three times at approximately 31, 34 and once at approximately 60 percent mass. Refer to paragraph 12.4 for the special test on the depletion sensor.

12.2 APS Electrical Control System

The APS Simulator No. 188B was utilized to verify the engine control functions of APS No. 1 and APS No. 2 during the acceptance firing.

Exhibits of the engine feed valves verified that the electrical control system operated within its prescribed limitations.

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* Hardwire measurements are in parenthesis.

Listed are the monitored results:

Measurement No.	Function	Specified Minimum Value	Actual Value
K0132	APS Eng 1-1/1-3 Feed Valves Open	3.2 vdc	4.2 vdc
K0133	APS Eng 1-2 Feed Valves Open	3.2 vdc	4.2 vdc
K0134	APS Eng 2-1/2-3 Feed Valves Open	3.2 vdc	4.0 vdc
K0135	APS Eng 2-2 Feed Valves Open	3.2 vdc	4.0 vdc

The specified minimum value of 3.2 vdc indicated that all of the feed valves were operating.

12.3 Electrical Power System

The electrical power system performed satisfactorily throughout the acceptance firing.

The battery voltage, current, and battery simulator temperature profiles are shown in figures 12-2 through 12-4.

12.3.1 Static Inverter-Converter

The static inverter-converter operated within its required limits during the firing. Its actual values are shown in the following table:

Characteristics	Maximum	Minimum	Acceptable Limits
Voltage (vrms)	114.50	114.30	115.0 ± 3.45
Voltage (vdc)	5.0	5.0	5.0 ± 0.5
Voltage (vdc)	21.8	21.7	21.0 $^{+1.5}_{-1.0}$
Frequency (cps)	400.5	400.7	400.0 ± 6.0

12.3.2 5-Volt Excitation Modules

The performance of the forward No. 1 and No. 2, and aft 5-volt excitation modules was satisfactory during the acceptance firing. The actual values are listed below:

Characteristics	Maximum	Minimum	Acceptable Limits
Aft Voltage (vdc)	5.03	5.02	5.0 $\pm$0.03
Forward 1 Voltage (vdc)	5.00	4.99	5.0 $\pm$0.03
Forward 2 Voltage (vdc)	4.99	4.98	5.0 $\pm$0.03

12.3.3 Chilldown Inverters

The chilldown inverters performed satisfactorily during the acceptance firing.

12.4 Special Depletion Sensor Test

During the first LH2 loading, LH2 depletion sensor No. 1 cycled one time for 28 ms at the 30 percent loading level.

On the second LH2 loading, the same sensor cycled three times for 7, 12, and 9 ms at 31, 34 and the 60 percent levels, respectively. No other abnormal cycles were noted during the remainder of the test. The cycles were of such short duration that the special test, prepared for use in case of depletion sensor cycling, could not be implemented.

A Simulated Wet Command was sent to sensor No. 1 at the 5 percent level on the third loading. This would define an open system between sensor and control unit if cycling should occur. No abnormal cycles occurred for the remainder of the test.

During the third loading, a helium bubble test was performed at approximately 86 and 40 percent LH2 level during detanking. Helium was bubbled at a rate of 30 scfm for 2 min. The helium was injected in the low pressure duct by way of the engine purge system. No abnormal depletion sensor activity was noted.

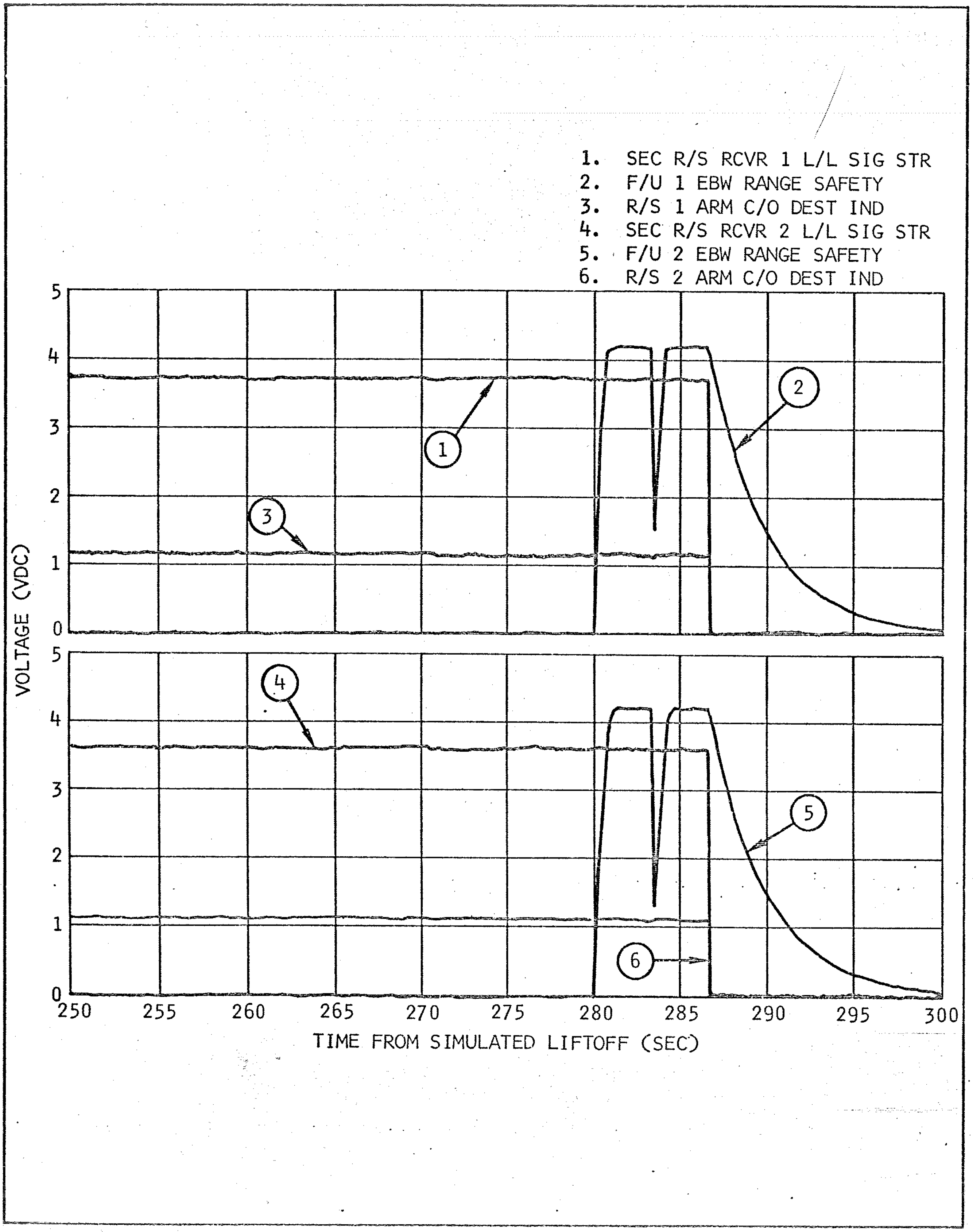

Figure 12-1. Secure Range Safety Command System Data

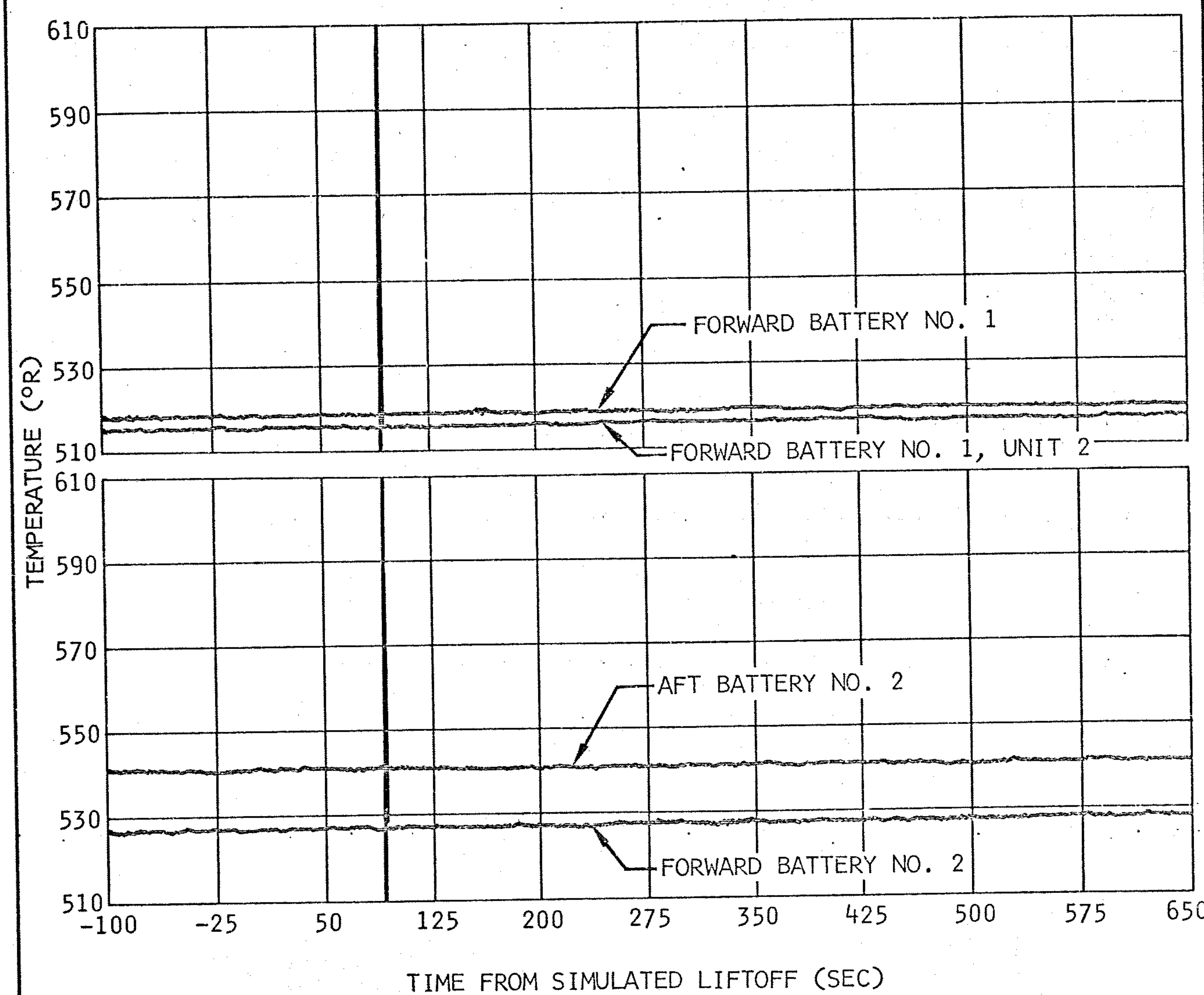

Figure 12-2. Battery Temperatures

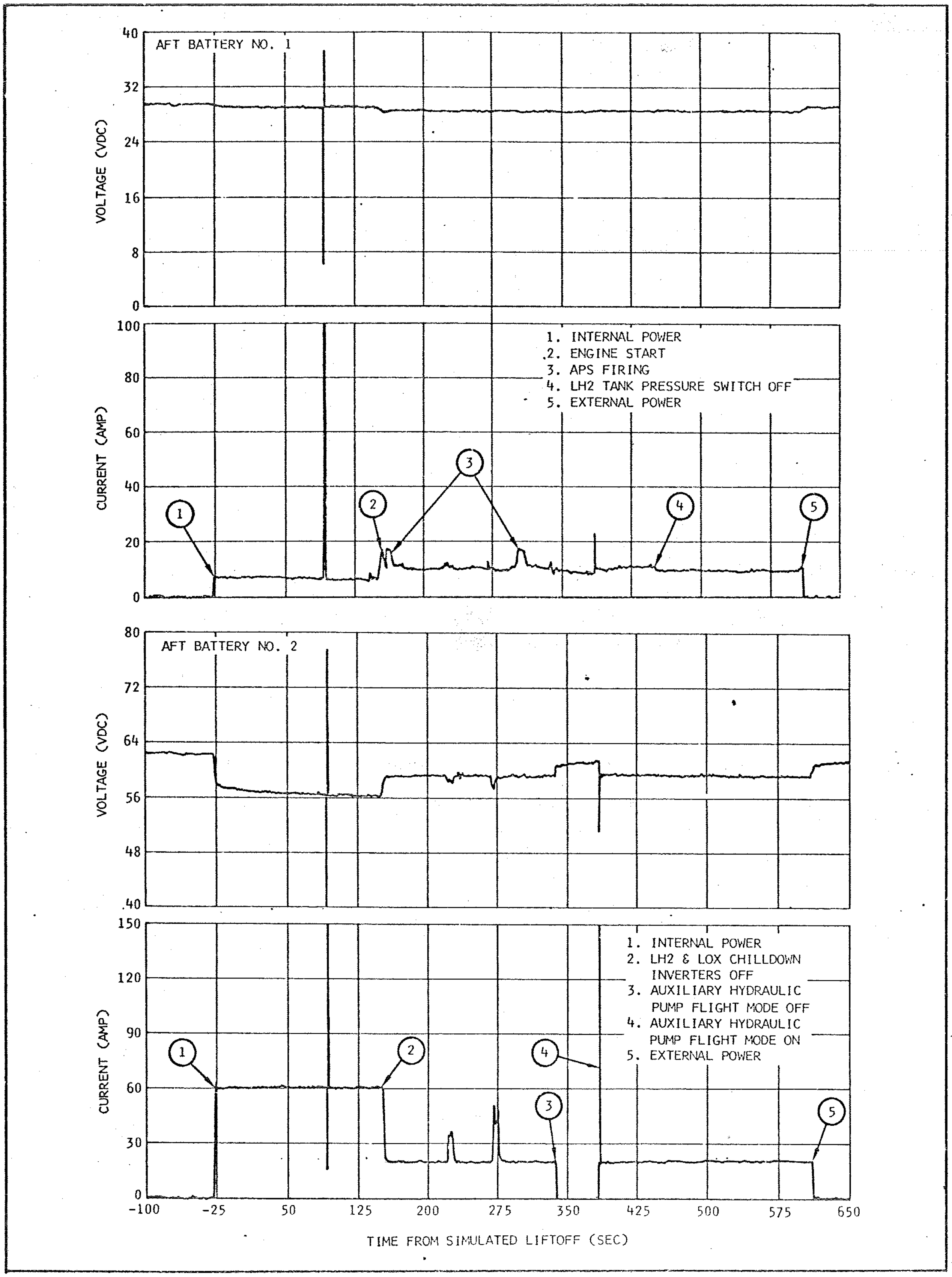

Figure 12-3. Aft Battery Voltage and Current Profiles

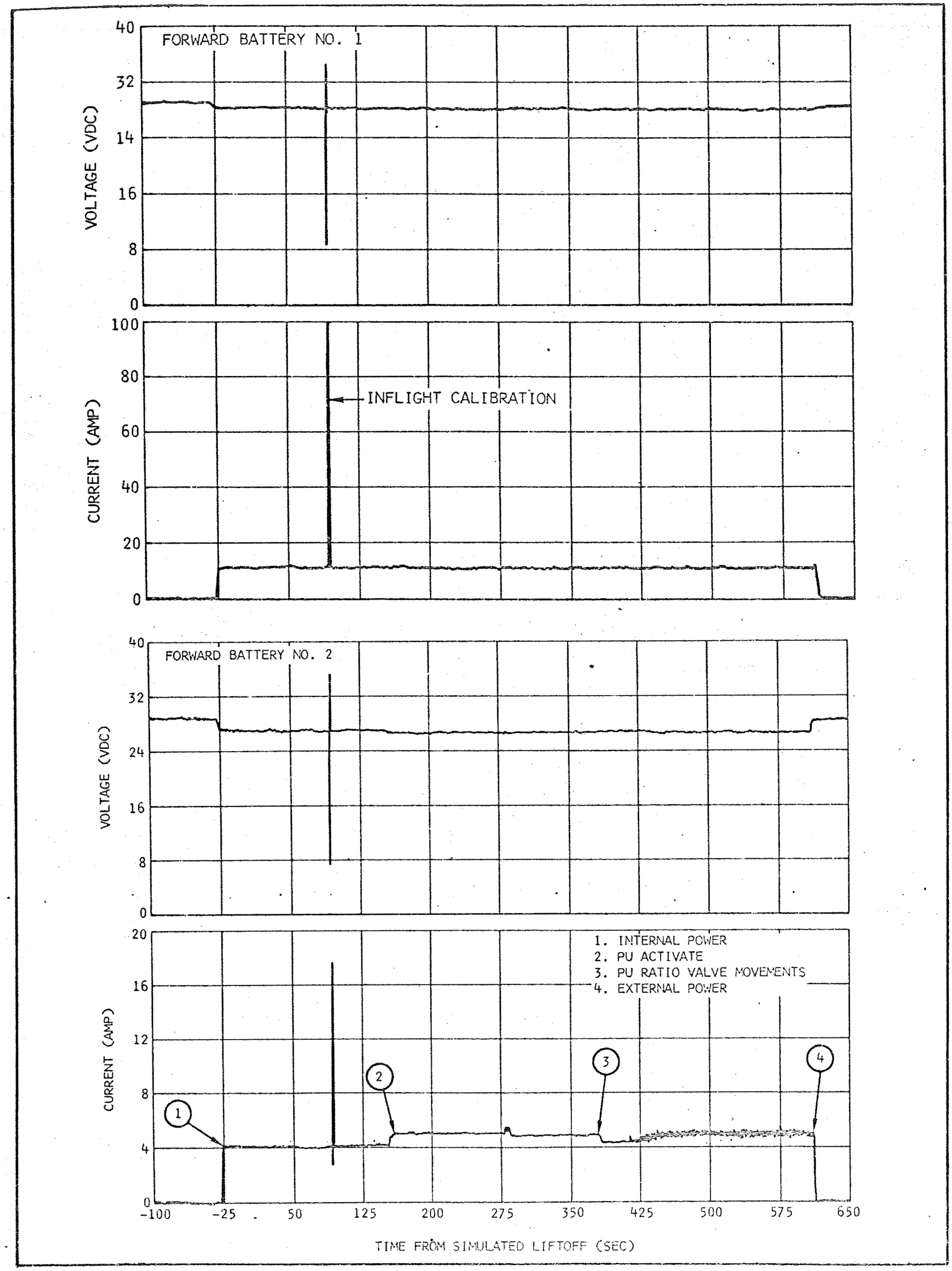

Figure 12-4. Forward Battery Voltage and Current Profiles

13

HYDRAULIC SYSTEM

13. HYDRAULIC SYSTEM

13.1 Hydraulic System Operation

The hydraulic system test program was conducted during countdown 614085, during which the engine was successfully positioned and gimbaled. System running time for this test, from auxiliary pump ON prior to simulated liftoff to auxiliary pump OFF following cutoff, was 1,316.5 sec.

The gimbal program was initiated after the engine start side loads subsided and the support links dropped. The auxiliary hydraulic pump was turned off after the gimbaling program for approximately 47 sec during the firing to verify satisfactory engine-driven pump operation.

Significant event times are presented in the following table:

Event	Approximate Time (sec)
Auxiliary pump ON	T_0 -693.5
Simulated Liftoff	T_0 +0
Engine-driven Pump Start	T_0 +153.2
Support Links Dropped	T_0 +187.2
Gimbal Program Start	T_0 +221.0
Gimbal Program Stop	T_0 +277.7
Auxiliary Pump OFF	T_0 +337.0
Auxiliary Pump ON	T_0 +384.0
Engine-driven Pump Stop	T_0 +610.7
Auxiliary pump OFF	T_0 +623.0

13.2 System Pressure at Salient Times

The GN2 accumulator precharge pressure was 2,309 psia at 53 deg F during prefire checkout and approximately 2,210 psia at 35 deg F after the acceptance firing. The pressure observed after the firing is equivalent to the acceptable precharge pressure limits of 2,300 to 2,400 psia at 68 deg F. Test data indicated that the auxiliary pump discharge pressure increased to 3,600 psia in 14.3 sec after energizing the pump motor. Acceptable pump pressure was maintained from T_0 -679.2 sec through T_0 -0. The simulated launch requirements were met.

During the brief period that the auxiliary pump was off, the engine-driven pump pressure was observed to be 3,650 psia. The engine-driven pump supplied the system leakage flow throughout the firing since its pressure compensator setting was sufficiently higher (3,650 versus 3,600 psia) than that of the auxiliary pump. The auxiliary pump however, shared some of the gimbal flow requirements as seen from fluctuation of the motor current demand.

GN2 pressure was similar to hydraulic system pressure with the pump(s) operating. The significant system pressures are shown in the following table:

TIME (sec)	SYSTEM PRESSURE (psia)	RESERVOIR PRESSURE (psia)
T_0 -679.2	3,600	161
T_0 +0 (simulated start)	3,600	180
T_0 +203 (after engine start transient)	3,650	178
T_0 +221 to (gimbal)	3,700	192
T_0 +277	3,590	160
T_0 +623 (prior to auxiliary pump OFF)	3,630	180

13.3 Reservoir Level at Salient Times

The reservoir level prior to system operation was 90 percent at an approximate average system oil temperature of 61 deg F (equivalent to 91.2 percent at 70 deg F). Minimum level during operation was 33 percent.

13.4 Temperature History

Hydraulic fluid and accumulator gas temperatures experienced during the hydraulic system test program were as follows:

TIME (sec)	ENGINE-DRIVEN PUMP INLET (deg F)	RESERVOIR (deg F)	ACCUMULATOR GN2 (deg F)
T_0 -693.5 (auxiliary pump ON)	50	33	73
T_0 +153.2 (ignition)	92	60	58
T_0 +221 (start gimbal)	110	62	61
T_0 +227.7 (stop gimbal)	97	67	
T_0 +610.7 (cutoff)	136	75	
T_0 +623 (auxiliary pump OFF	137	84	61

13.5 Engine Side Loads

Peak loads in the support links during engine start transients were as follows:

ITEM	PEAK LOAD (lbf)
Pitch Link	+12,000, -20,000
Yaw Link	+17,000, -32,000

13.6 Hydraulic Fluid Flowrates

Approximations from the reservoir fill and emptying rates are presented in the following table:

ITEM	FLOW (gpm)	ALLOWABLE (gpm)
System Internal Leakage	0.51	0.4 to 0.8
Auxiliary Pump Maximum Flowrate	1.77	1.5 min

13.7 Auxiliary Pump Motor Voltage and Current

Auxiliary pump motor electrical data were monitored only after the stage power source had switched to internal power (batteries) and after the chilldown pumps had shut down. The design requirements are as follows:

Voltage	51 to 61 vac
Maximum Starting Current	300 amp
Maximum Operating Current	85 amp

TIME (sec)	VOLTAGE SUPPLY (V)	CURRENT DEMAND (amp)
T_0 +153 (prior to ignition)	57.5	32.2
T_0 +160 (after ignition)	59	21
T_0 +221 to (gimbal) T_0 +277.2	59 maximum 57.5 minimum	37.5 maximum 21 minimum (52 maximum during 7 deg ramp)
T_0 +384 (turn auxiliary pump ON after brief shutdown)	52 min	155 peak
T_0 +610 (prior to cutoff)	59	21
T_0 +623 (prior to auxiliary pump OFF)	56.3	39

13.8 Thrust Offset

Approximate thrust offset was calculated from actuator differential pressures obtained prior to and following engine cutoff, using 164,000 lbf net thrust. The thrust offset was 0.273 in. from the stage longitudinal axis and 38.7 deg from fin plane 2 toward fin plane 1.

14

FLIGHT CONTROL SYSTEM

14. FLIGHT CONTROL SYSTEM

The dynamic response of the hydraulic servo thrust vector control system was measured while the J-2 engine was gimbaling during the acceptance firing of the S-IVB-209 stage. The performance of the pitch and yaw hydraulic servo control system was found to be acceptable.

14.1 Actuator Dynamics

The frequency response test of the pitch and yaw hydraulic servo control system for a ± 1/2-deg sinusoidal signal between 0.6 and 9 cps, and for a ± 1/4-deg sinusoidal signal between 0.6 and 2 cps verified the acceptability of the actuator responses. The acceptable limits and the gain and phase plots within these limits are presented in figures 14-1 and 14-2.

14.2 Engine Slew Rates

A nominal two-deg step command was applied to the pitch and yaw actuators from which the engine slew rates were determined. The minimum acceptable engine slew rate is 8 deg/sec, which corresponds to an actuator piston travel rate of 1.66 ips. A nominal slew rate for a 2-deg step without the effects of gimbal friction is 13.6 deg/sec. The measured values were found to be acceptable and are presented in the following table:

Actuator	Condition	Engine Travel (deg)	Engine Slew Rate deg/sec
Pitch	Retract	0.0 to +2.0	10.8
	Extend	+2.0 to 0.0	10.8
	Extend	0.0 to -2.0	10.9
	Retract	-2.0 to 0.0	10.7
Yaw	Extend	0.0 to +2.0	11.9
	Retract	+2.0 to 0.0	11.3
	Retract	0.0 to -2.0	11.4
	Extend	-2.0 to 0.0	11.8

The minimum engine slew rate obtained is 10.7 deg/sec. This corresponds to an actuator piston travel of 2.22 ips when using a conversion of 4.83 deg of engine movement per in. of actuator travel. Thus, in all cases, each actuator exceeded the minimum acceptable piston travel rate of 1.66 ips, or corresponding engine travel rate of 8 deg/sec.

14.3 Differential Pressure Feedback Network

The differential pressure feedback network in the pitch and yaw hydraulic servo-valves was operating properly since adequate system damping was demonstrated by observing the actuator differential pressure measurements during the 2-deg step response tests. The differential pressures decreased in amplitude as a function of time without sustained ringing. The recorded data are presented in figure 14-3.

14.4 Cross Axis Coupling

A minimum amount of cross axis coupling occurred as noted by the generated actuator differential pressure in the non-gimbaled plane.

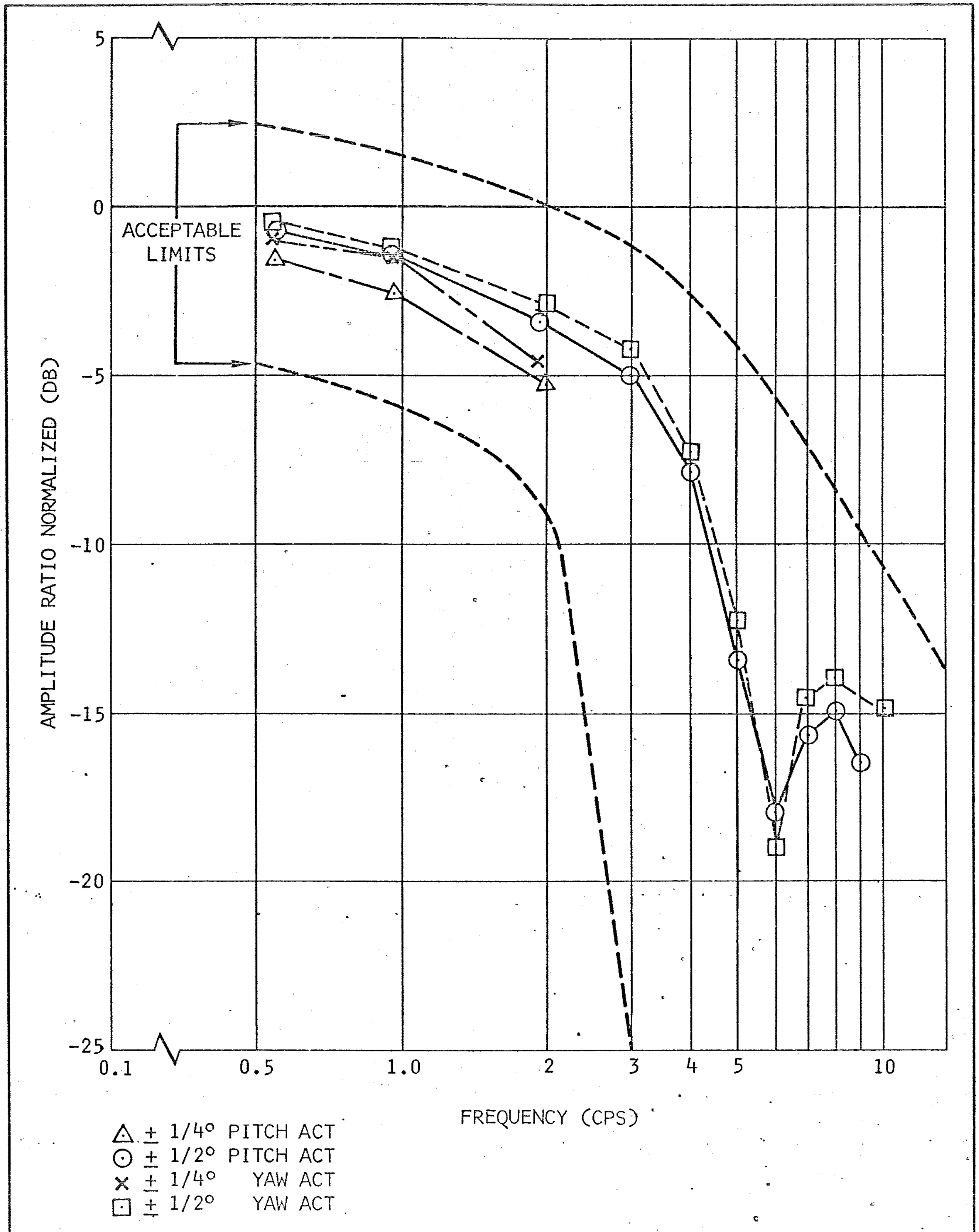

Figure 14-1. Actuator Response (Gain)

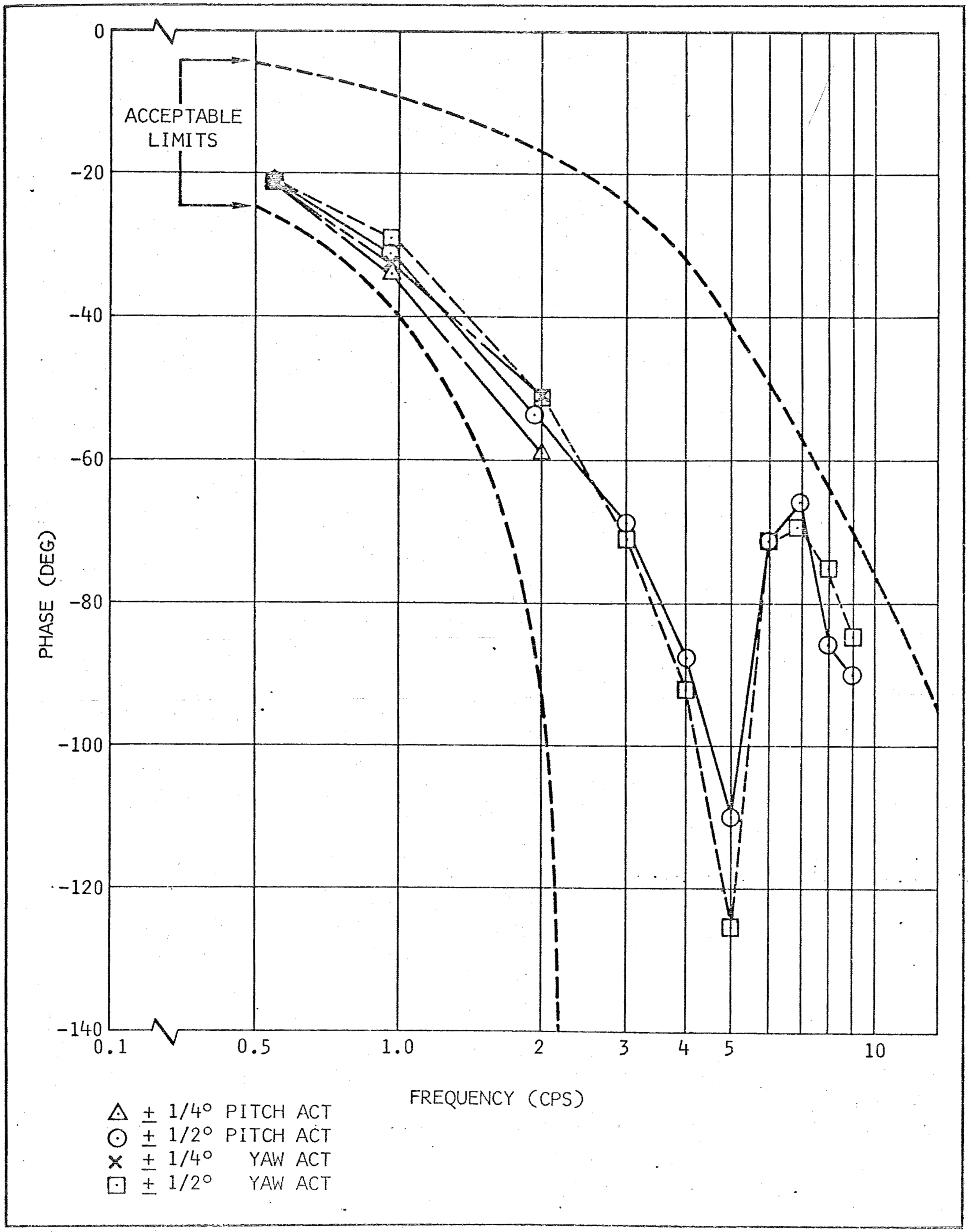

Figure 14-2. Actuator Response (Phase Lag)

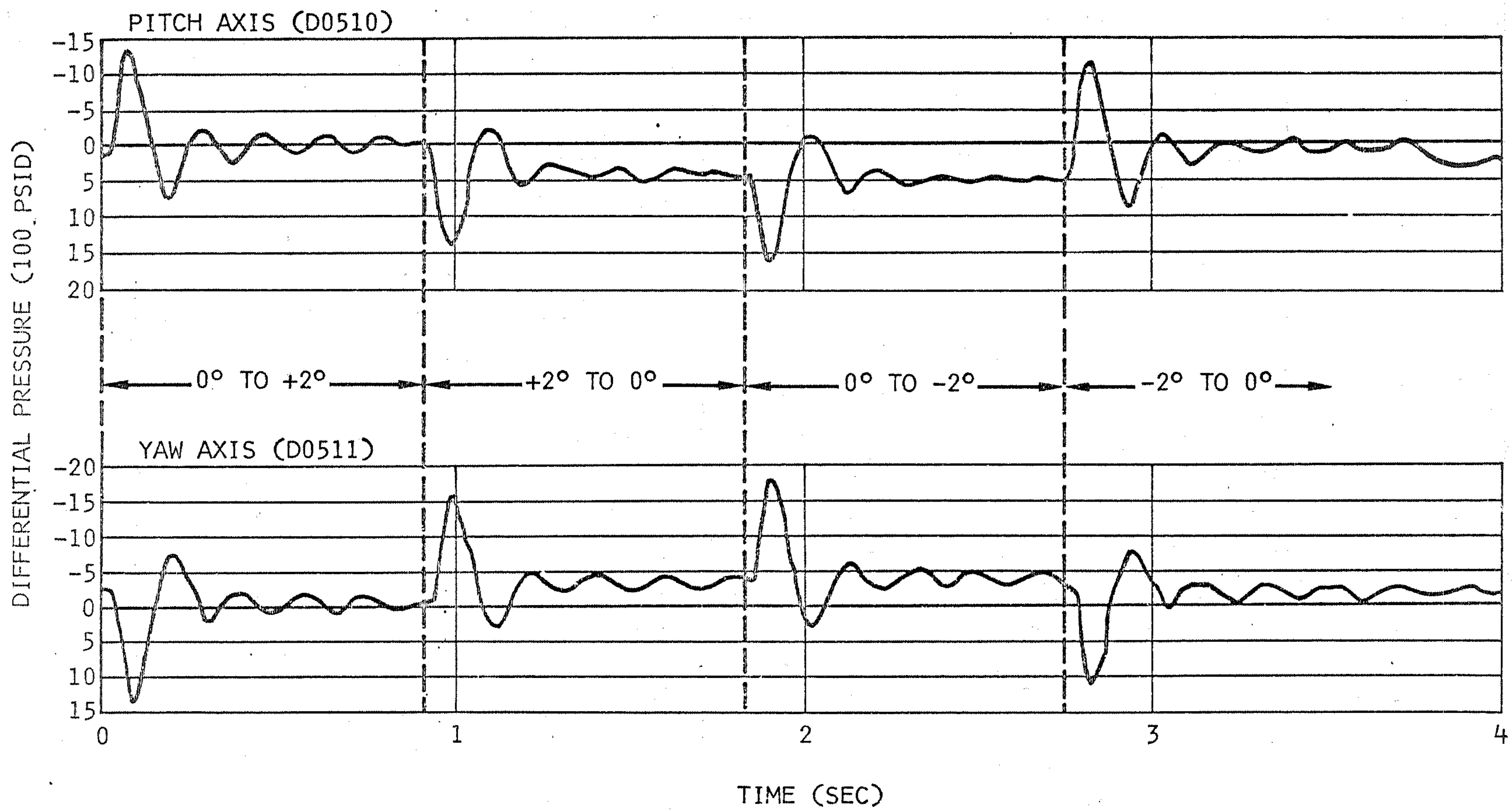

Figure 14-3. Actuator Differential Pressure (±2 Deg Transient Response)

15

STRUCTURAL SYSTEMS

15. STRUCTURAL SYSTEMS

Structural integrity of the S-IVB-209 stage was maintained for the vibration, temperature, and thrust load conditions of the acceptance firing. No structural irregularities were detected during the postfiring inspection, static firing, and cryogenic loading.

15.1 Common Bulkhead

The results of the gas sample surveys, combined with satisfactory common bulkhead pressure decay checks, indicate the bulkhead is sound and leak tight. An additional vacuum port location for common bulkhead internal pressure measurements was used for the second time, having been previously used with the S-IVB-503N stage. This port, located approximately 180 deg from the vacuum pump port, was located so the readings would be more indicative of general pressure conditions within the honeycomb filled bulkhead. It was found that during pumpdown of the common bulkhead, the pressure readings from the vacuum pump port dropped immediately to less than 1 psia; however, at the pressure port located 180 deg from the vacuum pump port the pressure gradually dropped to 10.5 psia in 6 hrs and to less than 1 psia in 9 days of pumpdown. Thus, it is evident that the newly added pressure measurement (D0237) is more accurate than the original vacuum pump port measurement (D0545) in indicating general pressure conditions within the bulkhead. During the actual acceptance firing, the bulkhead internal pressure readings from both transducers was less than 1 psia. Gas sample analyses consistently indicated negligible quantities of hydrogen and helium gases within the common bulkhead. The results of the pressure checks and gas surveys are presented in Douglas Report No. SM-37550, *S-IVB-209 Stage Acceptance Firing (15 Day) Report*, dated July 1967.

15.2 LH2 Tank Interior

LH2 tank internal inspections during buyoff have been discontinued in view of a series of recent S-IVB stages having virtually no tank nonconformities requiring repair; however, as a matter of routine verification, the tank interior will be visually inspected from the manhold when the S-IVB-209 stage is erected in the VCL after storage.

15.3 Exterior Structure

A visual inspection of the stage thrust structure, LOX tank aft dome, aft skirt, LH2 tank cylindrical section, LH2 tank forward dome, and forward skirt revealed no structural damage after the full duration acceptance firing. The inspection revealed no debonding of standoffs, tunnel clips, or the aft skirt purge membrane.

15.4 Malfunction of LOX Tank Pressure Regulator

As a result of a malfunction of the LOX tank pressure regulator, the LOX tank ullage pressure was abnormally low for a duration of 60 sec immediately following J-2 engine start. During this time a minimum LOX tank ullage pressure of 29.1 psia was obtained (refer to paragraph 7.1). Simultaneously, the LH2 tank ullage pressure was 33.7 psia. The corresponding LH2 and LOX pressure heads at the critical common bulkhead to aft dome joint were 0.8 and 2.7 psia respectively. The net differential pressure at the joint was -2.7 psid (negative pressures occur when LH2 tank pressure exceeds LOX tank pressure). The design pressure at the critical joint is -21.9 psid limit or -30.7 psid ultimate (reference page 386 of Douglas Report No. SM-46987, *Saturn S-IVB-202 Stage Flight Evaluation Report*); therefore, the critical common bulkhead to aft dome joint has adequate strength to resist the imposed negative pressure differential without detrimental effects.

16

THERMOCONDITIONING
AND PURGE SYSTEMS

16. THERMOCONDITIONING AND PURGE SYSTEMS

16.1 Aft Skirt Thermoconditioning and Purge System

The aft skirt GN2 purge was initiated prior to LOX loading and continued throughout the acceptance firing until the completion of tank purge. The purge system operated satisfactorily and was within the design limits.

16.1.1 Aft Skirt GN2 Flowrate

The GN2 purge flowrate of 3,400 scfm was maintained throughout the acceptance firing.

16.1.2 Aft Skirt GN2 Temperature

The GN2 temperature at the APS module thermoconditioning system outlet sensor (C0663) held constant at 90 deg F. The aft skirt umbilical inlet temperature (C0715) varied between 105 and 110 deg F throughout the acceptance firing.

16.1.3 Aft Skirt Umbilical Inlet Pressure

The umbilical inlet pressure (D0767) was approximately 1/2 psi (13.8 in. H_2O) throughout the firing.

16.1.4 Nonflight Hardware

a. APS Module

Model DSV-4B-188B APS simulators were used in place of the flight modules at APS positions 1 and 2. These substitutes functionally represent the flight module thermoconditioning system.

b. Aft Interstage

The model DSV-4B-540 dummy interstage was used to support the stage on the test stand.

16.2 Forward Skirt Environmental Control and Thermoconditioning System

The forward skirt GN2 purge was initiated prior to LOX loading and continued throughout the firing until the completion of the tank purges.

The model DSV-4B-359, thermoconditioning system servicer, supplied the methanol/water coolant fluid to the thermoconditioning system throughout the firing.

16.2.1 Forward Skirt GN2 Purge Flowrate

A flowrate of 500 scfm was maintained during the acceptance firing which was within the design requirement of 500-600 scfm.

16.2.2 Forward Skirt GN2 Temperature

The forward skirt GN2 internal temperature (C0768) was within 43 to 58 deg F which was above the minimum design requirement of 40 deg F.

16.2.3 Forward Skirt Internal Pressure

The forward skirt internal pressure was approximately 0.69 in. H_2O which is well below the relief valve setting of 2 in. of H_2O.

16.2.4 Forward Skirt Thermoconditioning System Temperature

The thermoconditioning system fluid inlet temperature (C0753) was maintained between 56 to 61 deg F which is within the design temperature range of 57 $\pm$7 deg F.

16.2.5 Nonflight Hardware

Model DSV-4B-359, Thermoconditioning System Servicer

The servicer supplies thermally conditioned fluid to the forward skirt cold plates during all field station operations requiring power to the forward skirt electronic equipment. When the S-IVB is staged, the cold plates will receive fluid from the NASA instrument unit thermoconditioning system.

17

RELIABILITY AND
HUMAN ENGINEERING

17. RELIABILITY AND HUMAN ENGINEERING

17.1 Reliability Engineering

All functional failures of Flight Critical Items (FCI) and Ground Support Equipment/Special Attention Items were investigated by Reliability Engineering. Significant malfunctions of FCI's documented are noted in table 17-1.

17.2 Human Engineering

A Human Engineering evaluation was conducted in support of the S-IVB-209 stage acceptance firing. No significant man-machine problems were identified.

TABLE 17-1 (Sheet 1 of 6)
FLIGHT CRITICAL COMPONENTS MALFUNCTIONS

P/N AND S/N	NAME	TROUBLE	CAUSE	ACTION TAKEN
1A48431-505 S/N D-1	Probe, Fuel Mass	The following discrepancies were discovered while performing assembly outline modification on LH2 mass probe, lower mount: 1. Retaining plug was installed in such a manner as to preclude removal without damage to plug. Peelings of plug around plug port indicated maximum force had been exerted to install the plug. 2. Kel-F plug was forced into split-sleeve. Should be loose fit. 3. Lock pin P/N 973491-1 appeared to be sawed off and rough filed on end. 4. Foreign material, rubber like, found on hollow end of lock pin.	To be determined.	The probe was removed and shipped to location A3 for further evaluation and disposition. The discrepant probe was replaced with a like configuration probe, S/N D-6.
1A49968-509 S/N 101	Valve, Propellant Tank Shutoff	During C/D 614086 (TR1046, Run 3A) with propellants loaded, no hardwire talkback was received from the valve when prevalves were commanded closed. The valve also exhibited a slow opening time (3.010 sec).	To be determined.	The valve was removed and sent to location A-MRCC for additional test and evaluation. The discrepant valve was replaced with a like configuration valve, S/N 109.

TABLE 17-1 (Sheet 2 of 6)
FLIGHT CRITICAL COMPONENTS MALFUNCTIONS

P/N AND S/N	NAME	TROUBLE	CAUSE	ACTION TAKEN
1A66212-505 S/N 015	Electronics Assembly, Inverter-Converter, Static	During prefiring system checkout, unit was found to be inoperative. No output was obtained with an input of 28 vdc.	To be determined.	The unit cover was removed at location A45 and the internal components inspected for signs of wire and module damage from heat or electrical shorting. No visible damage was noted. The unit was removed and routed to location A-MRCC for additional disposition, test, and possible SFA. The discrepant unit was replaced with a like configuration unit, S/N 00011.
1A66248-507 S/N 68	Actuator Assembly, Hydraulic	Nicks and scratch marks were found around the rod end of hydraulic actuator.	Caused by installation and removal of the mid-stroke locks. Due to the close tolerance between the lock and rod end, technicians must gently rock J-2 engine in order to install or remove locks. Using this method, the locking halves tend to penetrate the softer metal at the rod ends.	The nicks and scratches were removed with crocus cloth and hand stone. At the completion of rework and inspection, actuator was found acceptable by engineering for use.

TABLE 17-1 (Sheet 3 of 6)
FLIGHT CRITICAL COMPONENTS MALFUNCTIONS

P/N AND S/N	NAME	TROUBLE	CAUSE	ACTION TAKEN
1B42290-503 S/N 0025	Module, Control, LOX Tank Pressurization	During prefiring system checkout per procedure 1B71877, leakage of 2,500 scim was measured through the cold helium shutoff valve segment of the module. Maximum allowable leakage is 375 scim.	Not determined at location A45. Believed to be the shutoff valve main poppet seat (3 ply .010 mylar).	EWO 32607 revises Drawing 1B42290 and creates -505 configuration identical to the -503 except for the shutoff valve main poppet seats (Vespel, SP-1) and the addition of a circle-seal check valve in the top vent of the regulator. The module was routed to location A3-MRCC for further disposition. The discrepant module was replaced by a -505 configuration module, S/N 0037.
1B42290-503 S/N 0037	Module, Control, LOX Tank Pressurization	During C/D 614085 (TR1046, Run 2A) the output of the module regulator was 222 to 230 psia after mainstage ignition. The output should not exceed 410 $\pm$25 psig.	To be determined.	The module was sent to location A-MRCC for further investigation and test. The discrepant module was replaced with a like configuration module, S/N 0028.

TABLE 17-1 (Sheet 4 of 6)
FLIGHT CRITICAL COMPONENTS MALFUNCTIONS

P/N AND S/N	NAME	TROUBLE	CAUSE	ACTION TAKEN
1B43657-509 S/N 016	Module Assembly Pneumatic Power Control	During propulsion systems checkout at location A3-VCL, this module malfunctioned twice. The regulator discharge pressure went to approximately 600 psig. The regulator output should be 475 $\pm$25 psig. The regulator operated satisfactorily during seven tests that followed. Because the malfunction did not repeat, no FARR was written at A3 and the module was not replaced; however, the malfunction was recorded in location A3-SPB ROD #165 which is a description of the propulsion systems checkout at location A3.	During prefire checkout at location A45, FARR A245444 was written removing the module from the vehicle and FARR A245479 was written against the module. Engineering requested this action because of the malfunction noted on ROD #165 and because there was no information available at location A45 pertaining to this assembly. There was no malfunction of the module at location A45.	The module was removed and shipped back to location A3. It was dispositioned at A3 as "acceptable to engineering for use" due to the known history of the module (Ref. ROD #165). No further action will be taken regarding this case. The module was replaced with a like configuration module, S/N 022.
1B53920-501 S/N 51	Valve, Check, Chill System	The valve failed during the leak check per procedure 1B70773. The reverse leakage was 8,400 scim. The leakage should not exceed 6,000 scim.	To be determined.	The valve was removed and shipped to location A3-MRCC for evaluation and final disposition. The discrepant valve was replaced with a like configuration valve, S/N 040.

TABLE 17-1 (Sheet 5 of 6)
FLIGHT CRITICAL COMPONENTS MALFUNCTIONS

P/N AND S/N	NAME	TROUBLE	CAUSE	ACTION TAKEN
1B57781-501 S/N 0011	Module, Cold Helium Fill	During the checkout per procedure 1B57781, the reseat pressure was found to be 3,195 psig. The procedure calls for a reseat pressure between 3,200 and 3,500 psig.	Suspected improper adjustment of the relief valve.	The module was removed and shipped to the vendor for rework to -503 configuration. The discrepant module was replaced with a -503 configuration module, S/N 31. WRO S-IVB-3171 R2 1B58006 calls for replacing the 1B57781-501 module with a -503 configuration.
1B57781-503 S/N 0031	Module, Cold Helium Fill	The module failed during the test per procedure 1B57781 when removed from the stage and sent to A45 LOX Lab for test in compliance with 1B70773. The recorded cracking pressure was found to be 3,180 psig. The procedure calls for a cracking pressure between 3,200 and 3,500 psig.	Not determined at location A45.	The module was sent to location A-MRCC for evaluation and test. The failure mode could not be duplicated (cracking pressure was 3,280 psig) and the module was found to be acceptable to engineering for use. The module was returned to location A45 for installation on the stage.

TABLE 17-1 (Sheet 6 of 6)
FLIGHT CRITICAL COMPONENTS MALFUNCTIONS

P/N AND S/N	NAME	TROUBLE	CAUSE	ACTION TAKEN
1B57781-503 S/N 0031	Module, Cold Helium Fill	During C/D 614085 (Task 51) post-test securing, the cold helium fill valve was frozen in the "open" position. The valve could not be cycled at ambient temperature.	To be determined.	The module was removed and sent to the vendor for investigation and rework. The discrepant module was replaced with a like configuration module, S/N 0034.
103826 S/N J-2083	J-2 Engine	During engine field inspection prior to acceptance firing, the actuation time of the gas generator control valve was 128 ms instead of 140 ms.	To be determined.	Unit control pneumatics line was reorificed to correct valve timing. The .047 dia orifice was replaced by Rocketdyne with a .043 dia orifice. This is a GFE item.

AP 1

ENGINE PERFORMANCE
PROGRAM (PA49)

1. ENGINE PERFORMANCE PROGRAM (PA49)

This appendix contains the digital printout of computer program PA49 which is a compilation of computer programs AA89, G105, and F823. These computer programs are the methods employed in the propulsion system performance reconstruction of the S-IVB-209 stage acceptance firing. The performance analysis and associated plots are presented in section 6.

Printout symbols are presented in table AP 1-1 and the digital printout is contained in table AP 1-2.

TABLE AP 1-1
PROGRAM PA49 PRINTOUT SYMBOLS

FSUB1	Stage thrust from AA89 (lbf)
WDOTT1	Total flowrate from AA89 (lbm/sec
WDOTO1	LOX flowrate from AA89 (lbm/sec)
WDOTF1	LH2 flowrate from AA89 (lbm/sec)
EMR 1	Engine mixture ratio from AA89
ISP 1	Specific Impulse from AA89 (sec)
MSUBO1	LOX mass onboard from AA89 (lbm)
MSUBF1	LH2 mass onboard from AA89 (lbm)
FSUB2	Stage thrust from G105 (lbf)
WDOTT2	Total flowrate from G105 (lbm/sec)
WDOTO2	LOX flowrate from G105 (lbm/sec)
WDOTF2	LH2 flowrate from G105 (lbm/sec)
EMR 2	Engine mixture ratio from G105
ISP 2	Specific impulse from G105 (sec)
MSUBO2	LOX mass onboard from G105
MSUBF2	LH2 mass onboard from G105 (lbm)
FSUB 3	Stage thrust from F823 (lbf)
WDOTT3	Total flowrate from F823 (lbm/sec)
WDOTO3	LOX flowrate from F823 (lbm/sec)
ODOTF3	LH2 flowrate from F823 (lbm/sec)
EMR 3	Engine mixture from F823
ISP 3	Specific impulse from F823 (sec)
MSUBO3	LOX mass onboard from F823 (lbm)
MSUBF3	LH2 mass onboard from F823 (lbm)
FSUB4	Predicted stage thrust (lbf)
WDOTT4	Predicted total flowrate (lbm/sec)
WDOTO4	Predicted LOX flowrate (lbm/sec)
WDOTF4	Predicted LH2 flowrate (lbm/sec)
EMR 4	Predicted engine mixture ratio
ISP 4	Predicted specific impulse (sec)
MSUBO4	Predicted LOX mass onboard (lbm)
MSUBF4	Predicted LH2 mass onboard (lbm)
THRUST	Composite stage thrust (lbf)
T FLOW	Composite total flowrate (lbm/sec)
O FLOW	Composite LOX flowrate (lbm/sec)
F FLOW	Composite LH2 flowrate (lbm/sec)
EMR	Composite engine mixture ratio
ISP	Composite specific impulse (sec)
O MASS	Composite LOX mass onboard (lbm)
F MASS	Composite LH2 mass onboard (lbm)

TABLE AP 1-2 (Sheet 1 of 6)
ENGINE PERFORMANCE PROGRAM (PA49)

TIME				
FSUB 1	FSUB 2	FSUB 3	FSUB 4	THRUST
WDOTT1	WDOTT2	WDOTT3	WDOTT4	T FLOW
WDOTO1	WDOTO2	WDOTO3	WDOTO4	O FLOW
WDOTF1	WDOTF2	WDOTF3	WDOTF4	F FLOW
EMR 1	EMR 2	EMR 3	EMR 4	*EMR*
ISP 1	ISP 2	ISP 3	ISP 4	*ISP*
MSUBO1	MSUBO2	MSUBO3	MSUBO4	O MASS
MSUBF1	MSUBF2	MSUBF3	MSUBF4	F MASS
0.000				
0.000	0.000	0.000	0.000	0.000
0.000	3.475	1.479	0.000	1.651
0.000	3.416	0.260	0.000	1.225
0.000	0.059	1.219	0.000	0.426
0.000	57.810	0.214	0.000	19.341
0.000	0.000	0.000	0.000	0.000
193215.000	193215.000	193215.000	193273.000	193215.000
38047.000	38047.000	38047.000	38000.000	38047.000
1.000				
218.192	0.000	0.000	447.604	72.731
32.366	12.525	1.471	4.852	15.454
22.566	2.393	0.259	0.000	8.406
9.801	10.132	1.212	4.852	7.048
2.302	0.236	0.214	0.000	0.917
6.741	0.000	0.000	92.249	2.247
193190.209	193211.963	193214.303	193272.564	193205.488
38041.037	38041.021	38045.757	37995.167	38042.604
2.000				
16566.382	17136.406	16886.111	43407.979	16862.966
86.672	95.694	13.238	113.200	65.202
48.743	56.464	6.331	65.825	37.179
37.929	39.230	6.908	47.375	28.022
1.285	1.439	0.917	1.389	1.214
191.138	179.075	1275.534	383.462	548.583
193155.154	193196.154	193211.979	193234.223	193187.760
38020.645	38020.166	38042.367	37965.003	38027.725
3.000				
100344.920	112398.611	115683.021	165017.518	109475.517
188.671	211.030	249.568	355.977	216.423
135.475	156.302	199.878	291.929	163.885
53.196	54.729	49.691	64.048	52.538
2.547	2.856	4.022	4.559	3.142
531.853	532.618	463.533	463.562	509.334
193076.320	193107.203	193115.152	193077.646	193099.557
37974.264	37972.428	38011.133	37910.944	37985.941
4.000				
162647.129	187839.219	181765.482	216090.441	175750.609
361.517	409.682	422.531	494.556	397.910
292.199	338.117	344.338	416.029	324.835
69.318	71.564	78.193	78.527	73.075
4.215	4.725	4.404	5.298	4.448
449.901	446.296	430.183	436.939	442.127
192850.523	192845.170	192810.863	192703.844	192835.518
37913.138	37909.301	37938.550	37839.064	37920.330
4.100				
164367.402	184480.361	183206.680	217300.160	177351.479
367.832	417.095	426.703	496.897	403.877
297.719	344.341	347.107	417.984	329.722
70.114	72.753	79.597	78.914	74.154
4.246	4.733	4.361	5.297	4.447
446.854	442.299	429.354	437.314	439.502
192820.977	192811.002	192776.109	192662.098	192802.695
37906.140	37902.067	37930.573	37831.150	37912.926
4.110				
164439.486	184620.842	183359.926	217421.119	177473.416
368.472	417.769	427.051	497.131	404.431
298.290	344.928	347.478	418.179	330.229
70.192	72.841	79.573	78.952	74.202
4.249	4.735	4.367	5.297	4.451
446.283	441.927	429.363	437.351	439.191
192817.969	192807.523	192772.631	192657.904	192790.371
37905.432	37901.333	37929.775	37830.355	37912.180
5.000				
169376.621	190324.592	190325.650	224680.352	183342.285
393.050	444.489	442.030	513.151	426.523
318.078	367.127	365.074	431.440	350.093
74.973	77.361	76.956	81.711	76.430
4.243	4.746	4.744	5.280	4.577
430.929	428.188	430.572	437.845	429.896
192591.100	192487.582	192452.145	192279.053	192493.605
37840.153	37833.765	37861.228	37758.293	37845.048
6.000				
171703.811	193236.453	193126.275	231478.818	186022.176
398.970	452.683	449.890	543.930	433.848
322.884	373.921	371.144	460.637	355.963
76.087	78.762	78.746	83.293	77.865
4.244	4.748	4.713	5.530	4.568
430.367	426.869	429.274	425.567	428.837
192220.160	192116.314	192093.418	191834.910	192139.963
37764.319	37755.390	37782.752	37675.376	37767.467
6.100				
172181.662	193504.428	193350.928	231468.832	186345.672
399.457	453.117	450.387	543.905	434.320
323.314	374.454	371.602	460.613	356.457
76.143	78.663	78.785	83.291	77.864
4.246	4.760	4.717	5.530	4.574
431.040	427.051	429.299	425.569	429.130
192187.805	192078.850	192046.215	191788.803	192104.289
37756.678	37747.492	37774.847	37667.007	37759.672
6.200				
172676.055	193702.537	193716.355	231463.910	186764.980
399.991	453.562	451.308	543.892	434.953
323.796	374.996	372.422	460.601	357.071
76.194	78.566	78.886	83.291	77.882
4.250	4.773	4.721	5.530	4.581
431.700	427.511	429.233	425.570	429.481
192155.405	192041.332	192006.926	191742.699	192068.555
37749.030	37739.603	37766.931	37658.637	37751.854
6.205				
172715.932	193741.078	193754.781	231463.664	186803.930
400.115	453.629	451.403	543.891	435.049
323.918	375.060	372.509	460.601	357.162
76.197	78.569	78.894	83.291	77.887
4.251	4.774	4.722	5.530	4.582
431.660	427.532	429.228	425.570	429.475
192153.779	192039.451	192007.057	191740.395	192066.760
37748.647	37739.208	37766.535	37658.218	37751.463
7.000				
210552.756	213307.453	213299.707	231424.533	212386.637
481.549	487.773	499.087	543.790	489.470
400.850	408.351	417.740	460.505	408.930
80.700	79.422	81.347	83.286	80.489
4.967	5.142	5.135	5.529	5.031
437.240	437.309	427.380	425.577	433.976
191668.760	191731.275	191693.078	191373.903	191764.369
37686.180	37676.229	37702.544	37591.677	37688.317
8.000				
223923.020	222214.785	222104.746	231375.309	222747.516
522.651	520.343	520.476	543.663	521.157
440.217	438.667	438.238	460.384	439.040
82.435	81.676	82.238	83.279	82.116
5.340	5.371	5.329	5.528	5.347
428.437	427.054	426.734	425.586	427.408
191640.909	191303.113	191260.377	190913.023	191334.797
37604.382	37595.173	37620.375	37507.983	37605.643
9.000				
225602.471	223689.355	223438.328	231564.840	224243.333
529.275	527.300	523.940	544.143	526.838
446.334	444.964	441.115	460.845	444.138
82.941	82.336	82.825	83.303	82.701
5.381	5.404	5.326	5.532	5.370
426.248	424.217	426.458	425.555	425.641
190997.102	190860.604	190819.510	190451.971	190892.402
37521.230	37512.617	37537.421	37424.280	37523.756
10.000				
226359.891	224919.771	224580.496	231546.789	225386.719
531.993	530.236	526.931	544.101	529.722
448.791	447.606	444.675	460.800	447.024
83.207	82.630	82.256	83.301	82.698
5.394	5.417	5.406	5.532	5.406
425.490	424.188	426.774	425.559	425.484
190549.111	190413.920	190375.674	189990.880	190446.234
37437.817	37429.826	37454.544	37340.564	37440.729
15.000				
227753.350	227615.986	227687.143	231347.494	227752.153
534.973	536.958	533.825	543.589	535.252
452.181	454.589	451.380	460.317	452.717
82.791	82.368	82.445	83.272	82.535
5.462	5.519	5.475	5.528	5.485
425.729	424.272	426.521	425.593	425.507
188294.305	188154.090	188129.004	187685.773	188192.465
37021.073	37016.006	37042.137	36922.073	37026.495
20.000				
229172.553	228629.662	228668.777	231124.498	228823.664
538.082	538.836	535.451	543.047	537.456
455.762	456.544	453.946	459.824	455.384
82.320	82.292	81.605	83.223	82.072
5.536	5.548	5.561	5.525	5.549
425.907	424.303	427.058	425.615	425.756
186022.105	185673.205	185852.846	185383.088	185919.383
36606.350	36603.427	36632.377	36503.738	36614.051
25.000				
229344.350	228708.771	228631.775	231015.701	228894.963
538.924	540.143	535.586	542.816	538.218
456.541	457.962	453.778	459.662	456.094
82.383	82.181	81.810	83.154	82.124
5.542	5.573	5.547	5.528	5.554
425.560	423.423	426.880	425.587	425.238
183739.289	183583.590	183590.334	183082.484	183637.735
36192.600	36190.876	36222.163	36085.746	36201.880

TABLE AP 1-2 (Sheet 2 of 6)
ENGINE PERFORMANCE PROGRAM (PA49)

30.000				
230203.372	229598.783	229710.984	231048.240	229837.695
541.566	541.958	537.834	542.969	540.453
459.052	459.651	456.531	459.872	458.412
82.513	82.307	81.302	83.097	82.041
5.563	5.585	5.615	5.534	5.588
425.070	423.647	427.104	425.527	425.274
181448.459	181287.650	181311.668	180781.502	181349.258
35778.596	35778.290	35612.830	35668.061	35789.904
35.000				
230882.803	230174.469	230229.816	231093.746	230429.027
542.553	543.048	539.211	543.143	541.604
459.893	460.692	457.614	460.089	459.400
82.660	82.356	81.598	83.054	82.205
5.564	5.594	5.608	5.540	5.589
425.549	423.857	426.975	425.475	425.460
179148.822	178986.967	179027.656	178479.318	179054.480
35364.049	35365.256	35403.040	35250.641	35377.448
40.000				
231373.819	230455.939	230553.217	231134.127	230794.322
543.213	542.691	540.062	543.282	541.989
460.558	460.158	458.282	460.254	459.666
82.654	82.533	81.779	83.028	82.322
5.572	5.575	5.604	5.543	5.584
425.936	424.654	426.902	425.440	425.830
176845.154	176684.328	176740.193	176176.236	176756.557
34948.917	34951.314	34991.317	34833.374	34963.849
45.000				
231713.439	230716.520	230759.201	231188.123	231063.051
543.878	543.661	540.766	543.456	542.769
461.149	461.016	458.687	460.452	460.294
82.730	82.645	82.080	83.005	82.455
5.574	5.578	5.588	5.547	5.580
426.039	424.376	426.726	425.403	425.714
174538.254	174381.756	174450.393	173872.289	174456.799
34533.378	34536.708	34579.299	34416.233	34549.795
50.000				
231937.328	230733.049	230755.412	231264.244	231141.926
544.170	542.951	540.915	543.688	542.679
461.315	460.134	458.492	460.704	459.950
82.855	82.817	82.422	82.984	82.698
5.568	5.556	5.563	5.552	5.562
426.222	424.961	426.607	425.362	425.928
172230.164	172078.539	172160.664	171567.168	172156.455
34117.418	34121.288	34164.800	33994.201	34134.502
55.000				
231808.250	230510.623	230554.230	231343.498	230957.699
544.474	542.685	540.363	543.924	542.507
461.537	459.953	458.127	460.957	459.872
82.938	82.732	82.236	82.967	82.635
5.565	5.560	5.571	5.556	5.565
425.747	424.760	426.665	425.324	425.724
169920.830	169776.295	169871.209	169260.785	169856.109
33700.964	33705.727	33749.794	33582.267	33718.828
60.000				
231698.607	230249.908	230225.508	231426.367	230724.674
544.784	542.690	539.717	544.164	542.397
461.721	459.847	457.227	461.210	459.599
83.063	82.843	82.409	82.954	82.798
5.559	5.551	5.543	5.560	5.551
425.304	424.275	426.567	425.288	425.362
167610.426	167472.896	167577.441	166953.135	167554.254
33283.974	33289.486	33335.927	33165.402	33303.128
65.000				
231725.797	230505.027	230598.361	231110.682	230943.059
544.943	542.788	540.283	543.383	542.671
461.919	459.868	458.144	460.494	459.977
83.024	82.920	82.139	82.889	82.654
5.564	5.546	5.578	5.556	5.562
425.229	424.669	426.810	425.318	425.570
165299.385	165170.318	165287.811	164645.549	165252.504
32866.600	32873.003	32921.397	32748.674	32887.030
70.000				
231804.416	230433.721	230365.652	231024.195	230867.930
545.199	542.764	540.191	543.187	542.718
462.175	459.761	457.353	460.332	459.763
83.023	83.002	82.839	82.855	82.955
5.567	5.539	5.521	5.556	5.542
425.174	424.556	426.452	425.313	425.394
162987.262	162868.586	162995.559	162341.277	162950.459
32449.465	32456.199	32507.010	32332.260	32470.891
75.000				
231300.570	230024.672	230056.430	230938.418	230460.557
543.941	541.138	539.393	542.992	541.490
460.979	458.060	456.720	460.172	458.586
82.962	83.078	82.672	82.820	82.904
5.557	5.514	5.524	5.556	5.532
425.231	425.076	426.510	425.307	425.606
160677.854	160570.750	160707.918	160037.805	160652.172
32032.470	32039.148	32091.074	31916.021	32054.230
80.000				
231228.123	229497.680	229524.725	230852.713	230083.508
543.797	539.661	538.236	542.797	540.565
460.846	456.550	455.454	460.012	457.617
82.951	83.111	82.782	82.795	82.948
5.556	5.493	5.502	5.557	5.517
425.211	425.263	426.439	425.302	425.637
158371.453	158278.863	158425.752	157735.133	158358.688
31615.522	31622.187	31675.512	31499.955	31637.740
85.000				
230938.303	228621.932	228719.797	230773.119	229426.576
543.099	538.829	536.023	542.619	539.317
460.196	455.837	453.823	459.851	456.619
82.903	82.992	82.200	82.759	82.698
5.551	5.493	5.521	5.557	5.522
425.273	424.294	426.697	425.302	425.405
156066.801	155991.756	156149.447	155433.260	156069.332
31198.583	31205.596	31259.803	31084.046	31221.327
90.000				
231370.115	230093.227	229997.137	230695.768	230496.874
544.225	542.615	539.492	542.425	542.111
461.247	459.608	456.570	459.691	459.142
82.976	83.007	82.922	82.735	82.969
5.559	5.537	5.506	5.556	5.534
425.137	424.045	426.321	425.304	425.168
153759.213	153699.834	153868.121	153132.195	153775.723
30781.599	30788.622	30843.787	30668.257	30804.669
95.000				
231534.311	229945.049	229704.270	231023.041	230394.541
544.612	542.016	539.075	543.279	541.901
461.545	458.981	455.591	460.516	458.705
83.068	83.036	83.484	82.763	83.196
5.555	5.528	5.457	5.564	5.514
425.136	424.240	426.108	425.230	425.161
151449.777	151402.387	151582.730	150828.698	151478.297
30364.455	30371.839	30426.683	30252.427	30387.659
100.000				
231235.262	229369.447	229174.240	231107.541	229926.314
543.910	541.855	537.645	543.513	541.137
460.902	458.871	454.548	460.752	458.107
83.063	82.985	83.097	82.761	83.030
5.552	5.530	5.470	5.567	5.517
425.135	423.304	426.255	425.211	424.898
149139.279	149104.492	149296.543	148523.496	149150.104
29947.330	29955.156	30009.035	29836.561	29970.557
105.000				
231062.121	229155.977	229176.834	231189.301	229798.309
543.556	540.147	537.127	543.742	540.277
460.644	457.288	454.815	460.987	457.582
82.914	82.859	82.312	82.755	82.695
5.555	5.519	5.525	5.570	5.533
425.092	424.247	426.672	425.182	425.337
146832.596	146813.813	147018.801	146216.918	146888.402
29530.461	29539.221	29593.435	29420.715	29554.372
110.000				
230766.795	229079.936	229017.400	230901.168	229688.041
543.338	539.913	536.625	543.024	539.959
460.447	457.285	454.325	460.323	457.352
82.891	82.628	82.300	82.701	82.606
5.555	5.534	5.520	5.566	5.536
425.089	424.290	426.774	425.213	425.384
144526.952	144525.027	144741.805	143910.412	144597.938
29113.667	29123.708	29179.261	29004.964	29138.878
115.000				
230778.953	228694.182	228564.764	230834.988	229345.963
543.060	540.153	535.768	542.672	539.651
460.350	457.632	453.402	460.196	457.128
82.710	82.522	82.366	82.676	82.533
5.566	5.546	5.505	5.566	5.539
424.960	423.387	426.611	425.210	424.986
142222.357	142235.902	142466.660	141606.693	142308.395
28697.047	28708.170	28763.987	28589.465	28723.068
120.000				
230802.059	227896.627	227702.072	230768.875	228800.250
543.070	538.441	533.617	542.720	538.376
460.301	456.229	451.397	460.069	455.976
82.770	82.212	82.220	82.651	82.400
5.561	5.549	5.490	5.566	5.534
424.995	423.252	426.715	425.208	424.997
139918.277	139950.193	140195.666	139304.023	140021.377
28280.089	28292.965	28348.357	28174.093	28307.137
125.000				
231044.535	228667.521	228511.262	230703.789	229407.770
543.744	538.769	535.700	542.571	539.404
460.979	456.364	453.172	459.945	456.838
82.765	82.406	82.527	82.626	82.566
5.570	5.532	5.491	5.567	5.533
424.914	424.426	426.566	425.205	425.302
137612.045	137670.324	137932.430	137001.773	137738.266
27863.177	27878.176	27933.138	27758.847	27891.478

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130.000				
231193.363	229158.818	229113.889	230640.801	229822.020
544.009	541.855	536.715	542.424	540.887
461.258	459.240	454.736	459.821	458.411
82.832	82.615	81.979	82.604	82.475
5.569	5.559	5.547	5.567	5.558
424.918	422.915	426.881	425.204	424.905
135303.799	135374.078	135652.680	134700.146	135443.518
27445.771	27462.554	27517.966	27343.723	27475.431

135.000				
231302.555	229899.008	229853.121	230581.230	230351.559
544.287	542.008	536.786	542.281	541.694
461.353	459.373	456.437	459.695	459.054
82.933	82.635	82.351	82.586	82.640
5.563	5.559	5.543	5.566	5.555
424.965	424.162	426.612	425.206	425.246
132994.521	133076.582	133370.617	132399.143	133147.238
27028.289	27046.608	27103.355	26928.695	27059.417

140.000				
231063.334	229191.158	229048.811	230521.662	229767.766
543.704	540.789	536.822	542.138	540.438
460.819	458.340	454.453	459.570	457.869
82.890	82.449	82.368	82.569	82.569
5.559	5.559	5.517	5.566	5.545
424.980	423.809	426.676	425.208	425.155
130687.336	130778.176	131089.584	130098.782	130851.697
26610.730	26630.620	26688.657	26513.751	26643.335

145.000				
231095.178	229506.881	229336.443	230462.094	229979.500
543.629	541.069	537.847	541.995	540.848
460.599	458.264	454.902	459.444	457.922
83.030	82.805	82.944	82.551	82.927
5.547	5.534	5.484	5.566	5.572
425.097	424.173	426.397	425.210	425.222
128381.762	128485.414	128812.481	127799.060	128559.885
26193.278	26214.873	26272.787	26098.895	26226.979

150.000				
231234.395	229603.664	229505.066	230768.443	230114.375
543.731	539.780	538.154	542.790	540.555
460.442	457.114	455.373	460.209	457.643
83.289	82.666	82.781	82.581	82.912
5.528	5.530	5.501	5.573	5.520
425.274	425.365	426.467	425.152	425.702
126077.045	126194.485	126536.103	125496.728	126269.239
25776.021	25799.479	25857.905	25684.061	25811.155

155.000				
231068.311	228834.617	228913.041	230834.613	229605.320
543.593	539.074	536.453	542.973	539.707
460.549	456.320	454.351	460.394	457.073
83.044	82.754	82.103	82.579	82.634
5.546	5.514	5.534	5.575	5.531
425.076	424.496	426.716	425.131	425.429
123772.859	123905.771	124258.478	123195.016	123979.035
25358.835	25383.896	25443.600	25269.102	25395.444

160.000				
230954.521	229090.502	229148.635	230900.051	229731.219
543.329	539.845	536.770	543.156	539.461
460.291	457.221	454.850	460.580	457.454
83.037	82.624	81.920	82.576	82.527
5.543	5.534	5.552	5.578	5.543
425.073	424.363	426.903	425.109	425.447
121469.287	121617.765	121981.846	120890.373	121689.631
24941.601	24968.459	25029.514	24854.159	24979.858

165.000				
230989.846	229343.541	229330.332	230965.398	229887.906
543.392	539.865	537.607	543.338	540.248
460.291	457.143	455.156	460.766	457.530
83.101	82.722	82.451	82.572	82.758
5.539	5.526	5.520	5.580	5.529
425.039	424.817	426.576	425.086	425.494
119166.416	119330.369	119706.839	118534.804	119401.207
24524.561	24553.376	24610.323	24439.234	24564.753

170.000				
230860.598	229466.367	229460.584	230644.340	229929.182
543.143	539.130	538.006	542.530	540.073
460.099	456.576	455.537	460.011	457.404
83.043	82.555	82.469	82.519	82.649
5.540	5.531	5.524	5.575	5.532
425.046	425.623	426.502	425.127	425.724
116864.027	117044.691	117435.060	116281.288	117114.592
24107.313	24138.471	24201.125	24024.485	24148.969

175.000				
231170.816	229298.293	229230.768	230595.604	229899.957
543.993	540.415	537.425	542.418	540.611
460.925	457.666	454.853	459.917	457.815
83.068	82.749	82.572	82.501	82.796
5.549	5.531	5.509	5.575	5.529
424.952	424.300	426.535	425.126	425.263
114560.072	114758.298	115160.104	113979.278	114626.157
23690.156	23723.172	23787.213	23609.881	23733.313

180.000				
231392.582	229397.420	229433.320	230546.867	230074.441
544.420	540.945	537.723	542.305	541.031
461.170	458.232	455.569	459.823	458.374
83.256	82.713	82.154	82.482	82.708
5.539	5.540	5.545	5.575	5.542
425.021	424.068	426.676	425.124	425.255
112253.864	112465.622	112880.761	111677.738	112533.415
23272.402	23307.525	23372.597	23195.369	23317.508

185.000				
231108.510	230178.932	230076.506	230498.135	230454.648
543.942	540.384	539.634	542.193	541.320
460.912	457.670	456.641	459.729	458.408
83.030	82.714	82.993	82.464	82.912
5.551	5.533	5.502	5.575	5.529
424.677	425.955	426.356	425.122	425.729
109946.636	110171.932	110600.309	109376.671	110239.675
22854.806	22891.932	22957.398	22780.948	22901.378

190.000				
231238.355	229423.014	229583.527	230449.402	230081.797
544.286	541.379	537.665	542.080	541.110
461.210	458.596	456.032	459.634	458.613
83.076	82.782	81.533	82.446	82.497
5.552	5.540	5.586	5.575	5.559
424.848	423.776	427.001	425.120	425.208
107638.847	107876.855	108318.113	107076.073	107944.604
22437.157	22476.278	22543.244	22366.618	22485.560

195.000				
231009.039	228692.658	228325.367	230173.885	229509.025
543.541	540.123	535.692	541.716	539.852
460.319	457.351	454.253	459.590	457.311
83.221	82.767	81.639	82.126	82.540
5.531	5.526	5.564	5.596	5.541
425.008	423.409	426.999	424.898	425.139
105333.590	105584.228	106037.791	104775.874	105651.868
22019.749	22060.622	22129.760	21952.328	22070.043

200.000				
230551.649	228968.250	228841.367	230144.672	229553.555
543.355	540.052	536.698	541.626	540.035
460.317	457.294	453.918	459.491	457.177
83.037	82.759	82.780	82.134	82.858
5.544	5.526	5.483	5.594	5.518
424.863	423.974	426.387	424.914	425.075
103029.166	103295.668	103761.566	102475.980	103362.134
21602.368	21645.258	21715.750	21537.922	21654.458

205.000				
230795.479	228586.463	228596.844	230114.650	229322.926
543.241	539.954	535.671	541.535	539.622
460.198	457.291	453.606	459.392	457.032
83.042	82.663	82.065	82.142	82.590
5.542	5.532	5.527	5.593	5.534
424.843	423.344	426.730	424.931	424.974
100725.702	101009.271	101489.730	100176.581	101074.900
21184.892	21230.025	21300.543	21123.473	21238.487

210.000				
230675.832	228755.828	228450.945	230084.615	229294.199
543.143	539.485	535.991	541.444	539.541
460.262	457.009	452.853	459.293	456.708
82.886	82.476	83.138	82.150	82.833
5.553	5.541	5.447	5.591	5.514
424.702	424.027	426.221	424.947	424.983
98422.320	98723.271	99219.932	97877.677	98788.598
20767.336	20814.707	20884.644	20708.984	20822.229

215.000				
230631.277	228707.297	228610.787	230054.590	229316.453
542.974	539.392	535.940	541.353	539.435
460.003	456.766	453.457	459.194	456.742
82.772	82.627	82.483	82.158	82.694
5.544	5.526	5.498	5.589	5.573
424.756	424.009	426.561	424.963	425.108
96119.513	96437.315	96949.517	95579.271	96502.114
20349.646	20399.341	20469.758	20294.455	20406.248

220.000				
230510.975	228443.651	228369.658	230026.316	229107.893
542.725	538.122	535.191	541.263	538.679
459.785	455.839	453.043	459.095	456.223
82.940	82.283	82.147	82.169	82.457
5.544	5.540	5.515	5.587	5.533
424.779	424.519	426.707	424.980	425.318
93417.505	94153.077	94681.165	93281.357	94217.248
19931.752	19983.855	20055.758	19879.883	19990.455

225.000				
230582.990	228663.945	228659.045	230375.488	229298.992
542.827	538.629	535.481	542.138	539.112
459.755	456.012	453.613	459.906	456.463
83.063	82.617	82.267	82.232	82.649
5.535	5.520	5.514	5.593	5.573
424.782	424.530	426.681	424.939	425.331
91516.091	91870.002	92413.381	90982.659	91933.324
19513.798	19568.706	19640.604	19465.177	19574.369

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ENGINE PERFORMANCE PROGRAM (PA49)

230.000				
230503.969	228702.451	228408.264	230433.051	229204.893
542.771	538.175	535.716	542.756	538.837
459.812	455.857	452.680	460.009	456.116
82.959	82.318	83.036	82.257	82.771
5.543	5.538	5.452	5.592	5.511
424.680	424.959	420.361	424.944	425.333
89214.864	89586.639	90146.851	88680.671	89649.457
19095.469	19153.368	19227.176	19050.197	19156.671
235.000				
230600.984	229006.896	228783.252	230490.613	229463.707
542.875	538.612	536.602	542.395	539.363
459.733	456.255	453.683	460.113	456.557
83.142	82.357	82.919	82.282	82.806
5.529	5.540	5.471	5.592	5.514
424.777	425.179	426.356	424.950	425.437
86914.289	87304.299	87879.477	86378.165	87366.021
18677.114	18738.299	18813.375	18635.091	18742.929
240.000				
230424.545	228199.469	228022.301	230773.107	228892.104
542.545	538.222	534.413	542.774	538.393
459.499	455.887	452.011	460.167	455.799
83.046	82.335	82.402	82.607	82.594
5.533	5.537	5.485	5.571	5.519
424.711	423.987	426.678	425.174	425.126
84614.110	85023.039	85612.649	84075.267	85083.266
18258.824	18323.190	18399.684	18219.939	18327.232
245.000				
230887.357	228670.785	228514.117	230805.287	229357.418
543.644	538.728	535.852	542.872	539.408
460.420	456.218	453.154	460.273	456.598
83.224	82.510	82.698	82.598	82.811
5.532	5.529	5.480	5.572	5.514
424.703	424.464	426.450	425.156	425.216
82313.562	82743.814	83348.206	81771.967	82401.859
17840.345	17908.275	17986.666	17804.870	17911.742
250.000				
230747.621	228871.473	228636.881	230837.447	229435.322
543.445	539.806	536.122	542.969	539.791
460.345	457.468	453.617	460.380	457.143
83.100	82.338	82.505	82.589	82.648
5.540	5.556	5.498	5.574	5.531
424.601	423.989	426.557	425.139	425.049
80009.083	80456.938	81076.898	79468.133	80514.306
17421.688	17492.625	17573.986	17389.846	17496.066
255.000				
229794.588	227836.068	227715.613	230494.393	228446.754
540.678	537.280	533.399	542.108	537.319
457.140	454.600	451.315	459.578	454.352
83.538	82.680	82.683	82.530	82.967
5.472	5.498	5.458	5.569	5.476
425.012	424.055	426.435	425.182	425.167
77710.004	78172.430	78806.871	77167.554	78229.768
17002.380	17076.724	17158.162	16975.074	17079.089
260.000				
223924.535	222631.795	222534.674	230445.689	223030.332
525.802	525.765	521.162	542.000	524.243
442.744	443.464	439.245	459.492	441.818
83.058	82.301	81.917	82.508	82.425
5.331	5.388	5.362	5.569	5.360
425.873	423.444	426.997	425.177	425.438
75451.570	75924.387	76575.120	74867.687	75983.691
16582.956	16662.443	16746.202	16560.425	16663.867
265.000				
214601.408	214324.076	214138.553	230396.750	214354.676
502.927	506.028	501.393	541.891	503.449
421.301	424.442	419.773	459.404	421.838
81.627	81.586	81.620	82.486	81.611
5.161	5.202	5.143	5.569	5.169
426.705	423.542	427.068	425.172	425.778
73295.073	73754.913	74427.899	72568.257	73825.961
16169.990	16251.125	16335.835	16145.685	16252.317
270.000				
206709.791	206840.014	206796.783	230051.418	206782.195
483.810	486.081	482.947	540.959	484.946
403.523	407.631	403.134	458.395	404.762
80.287	80.450	79.813	82.564	80.184
5.026	5.067	5.051	5.552	5.048
427.259	423.782	428.198	425.266	426.411
71231.202	71668.431	72363.411	70270.120	71754.348
15763.117	15843.949	15930.039	15731.363	15845.702
275.000				
201370.197	200034.133	200055.172	223479.461	200486.500
470.785	470.108	466.212	524.267	469.035
391.408	390.790	387.625	442.086	389.941
79.377	79.318	78.588	82.181	79.074
4.931	4.927	4.932	5.379	4.930
427.733	425.507	429.108	426.270	427.449
69243.956	69673.234	70389.594	68007.832	69768.928
15362.013	15443.803	15532.526	15316.178	15446.114

280.000				
197673.564	195816.006	195879.963	212172.150	196456.310
461.695	459.894	455.636	496.622	459.075
382.803	381.518	378.232	416.203	380.851
78.892	78.375	77.404	80.419	78.224
4.852	4.868	4.886	5.175	4.869
428.148	425.785	429.904	427.230	427.946
67307.204	67742.255	68473.479	65864.005	67840.979
14964.598	15048.131	15140.815	14908.052	15051.181
285.000				
195417.086	192695.625	192660.266	202899.924	193590.992
456.295	452.095	448.044	473.966	452.145
377.873	374.304	370.756	395.058	374.311
78.422	77.791	77.288	78.928	77.834
4.818	4.812	4.797	5.005	4.809
428.269	426.228	430.003	428.071	428.166
65403.444	65852.586	66599.133	63837.799	65951.721
14569.508	14655.661	14751.920	14507.793	14659.030
290.000				
193680.838	190606.422	190548.420	196688.055	191611.891
451.917	447.172	443.047	458.938	447.379
373.634	369.456	365.763	381.030	369.618
78.284	77.716	77.284	77.907	77.761
4.773	4.754	4.733	4.891	4.753
428.575	426.249	430.086	428.572	428.303
63522.610	63992.992	64755.215	61898.172	64090.272
14176.039	14265.815	14364.452	14113.855	14268.769
295.000				
192787.408	189353.791	189121.779	193030.309	190254.324
448.692	443.420	439.709	450.000	443.940
370.798	366.154	362.174	372.667	366.375
77.894	77.265	77.534	77.333	77.565
4.760	4.739	4.671	4.819	4.723
428.551	427.031	430.107	428.956	428.563
61660.328	62152.583	62930.924	60013.168	62247.944
13783.991	13877.192	13977.902	13723.793	13879.692
300.000				
191050.074	188645.484	188364.674	190125.143	189353.408
446.193	442.036	438.108	443.736	442.112
368.959	364.767	360.371	367.571	364.609
77.234	77.268	77.737	76.165	77.413
4.777	4.721	4.636	4.826	4.711
428.178	426.765	429.950	428.464	428.298
59809.049	60322.583	61119.355	58161.987	60416.993
13392.747	13489.381	13590.129	13335.994	13490.752
305.000				
190542.963	187396.508	187266.490	188652.568	188401.984
444.820	439.516	434.634	440.120	439.657
367.517	363.027	358.427	364.142	362.991
77.301	76.489	76.207	75.978	76.666
4.754	4.746	4.703	4.793	4.735
428.360	426.370	430.860	426.639	428.530
57966.091	58501.229	59323.294	56331.313	58596.871
13001.739	13102.252	13201.529	12949.262	13101.840
310.000				
190120.262	187199.936	186835.533	187737.891	188068.574
443.888	439.783	433.859	437.860	439.177
366.748	363.487	357.324	361.984	362.520
77.140	76.296	76.535	75.876	76.657
4.754	4.764	4.669	4.771	4.729
428.307	425.664	430.752	428.763	428.241
56128.856	56685.719	57530.357	54514.366	56781.637
12611.180	12715.557	12813.706	12563.288	12713.481
315.000				
189678.692	186948.998	186595.947	187257.164	187741.012
442.825	438.214	433.348	436.653	438.129
365.767	362.024	356.567	360.808	361.453
77.057	76.189	76.781	75.845	76.676
4.747	4.752	4.644	4.757	4.714
428.334	426.616	430.590	428.847	428.515
54295.222	54874.120	55741.103	52705.692	54970.147
12220.597	12329.335	12426.804	12177.696	12325.609
320.000				
189815.697	186387.502	186832.641	187085.795	187845.277
442.907	438.510	433.180	436.197	438.199
365.580	362.296	357.631	360.332	361.834
77.322	76.223	75.549	75.865	76.365
4.728	4.753	4.734	4.750	4.738
428.563	426.188	431.305	428.902	428.687
52464.004	53064.015	53957.193	50900.862	53161.737
11830.227	11943.303	12038.656	11792.147	11937.395
325.000				
189650.822	187242.840	186920.406	187055.688	187938.020
442.672	438.181	434.165	435.084	438.340
365.533	361.898	357.277	360.184	361.570
77.138	76.283	76.689	75.900	76.770
4.739	4.744	4.647	4.746	4.710
428.423	427.318	430.527	428.945	428.756
50633.631	51254.553	52168.851	49097.494	51352.344
11439.747	11557.303	11652.495	11406.503	11549.921

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330.000				
189571.525	187028.760	186638.914	187097.633	187813.064
442.498	437.548	433.690	436.151	437.912
365.402	361.280	357.313	360.214	361.331
77.096	76.267	76.378	75.936	76.580
4.740	4.737	4.678	4.744	4.718
428.412	427.448	430.812	428.975	428.891
48802.897	49444.703	50379.363	47294.370	49542.320
11049.183	11171.256	11267.342	11020.715	11162.593
335.000				
189691.801	185864.348	186663.916	187175.697	187740.020
442.759	437.706	433.215	436.315	437.893
365.602	361.291	356.800	360.348	361.231
77.157	76.415	76.415	75.967	76.662
4.738	4.728	4.669	4.743	4.712
428.431	426.917	430.881	428.992	428.743
46972.662	47634.567	48591.166	45490.807	47732.798
10658.549	10785.201	10831.603	10634.813	10775.118
340.000				
189772.334	186971.557	186784.201	187278.559	187842.695
442.847	436.818	433.509	436.540	437.725
365.583	360.685	357.187	360.539	361.152
77.264	76.133	76.321	76.001	76.573
4.732	4.738	4.680	4.744	4.716
428.528	428.030	430.866	429.007	429.141
45141.814	45824.765	46804.269	43686.416	45923.615
10267.606	10399.213	10496.539	10248.795	10387.786
345.000				
189613.117	186656.818	186378.834	187390.668	187549.588
442.539	437.235	432.678	436.786	437.494
365.371	361.067	356.169	360.751	360.869
77.168	76.168	76.509	76.035	76.615
4.735	4.740	4.655	4.745	4.710
428.466	426.903	430.757	429.022	428.709
43313.141	44014.617	45018.105	41881.005	44115.287
9876.907	10013.106	10108.595	9862.652	9999.536
350.000				
189324.566	186419.168	186123.307	187523.387	187289.018
441.832	437.639	431.987	437.082	437.153
364.701	361.406	355.552	361.007	360.553
77.131	76.233	76.435	76.076	76.600
4.728	4.741	4.652	4.745	4.707
428.499	425.966	430.854	429.034	428.439
41485.209	42204.945	43231.898	40074.458	42307.351
9486.188	9627.040	9724.229	9476.374	9611.819
355.000				
189420.098	186525.699	186215.744	187645.537	187387.130
441.894	437.237	432.237	437.360	437.123
364.592	361.151	355.770	361.250	360.505
77.302	76.086	76.467	76.110	76.618
4.716	4.747	4.653	4.745	4.705
428.655	426.601	430.818	429.041	428.691
39659.408	40397.737	41449.476	38266.571	40502.207
9095.514	9241.367	9335.565	9089.936	9224.149
360.000				
189241.742	186744.791	186545.891	187674.531	187510.807
441.571	436.374	432.993	437.420	436.979
364.407	360.114	356.531	361.296	360.351
77.165	76.259	76.462	76.124	76.629
4.722	4.722	4.663	4.746	4.703
428.564	427.947	430.829	429.049	429.113
37833.830	38591.336	39667.066	36457.922	38697.410
8704.784	8855.628	8946.715	8703.390	8836.375
365.000				
189138.736	185983.166	185682.760	187609.213	186934.885
441.255	436.597	430.925	437.250	436.259
364.040	360.531	354.609	361.128	359.727
77.215	76.066	76.316	76.123	76.572
4.715	4.740	4.647	4.744	4.700
428.638	425.984	430.894	429.066	428.505
36010.757	36785.949	37887.222	34649.619	36894.643
8314.173	8470.150	8561.534	8316.815	8448.619
370.000				
188785.002	185936.451	185783.574	187485.500	186835.008
440.484	436.152	430.842	436.940	435.826
363.415	360.044	355.025	360.827	359.495
77.069	76.108	75.817	76.113	76.331
4.715	4.731	4.683	4.741	4.710
428.595	426.311	431.210	429.088	428.702
34190.088	34985.175	36109.337	32842.526	35094.860
7923.622	8084.650	8175.094	7930.272	8061.122
375.000				
188443.535	185750.744	185592.955	187354.248	186595.742
439.642	434.697	430.442	436.610	434.927
362.611	358.517	354.404	360.505	358.511
77.031	76.180	76.037	75.105	76.416
4.707	4.706	4.661	4.737	4.691
428.627	427.311	431.168	429.111	429.036
32373.448	33186.371	34336.714	31037.059	33298.844
7533.424	7699.394	7788.234	7543.782	7673.684
380.000				
188597.887	185933.650	185837.215	187227.805	186789.542
439.816	434.963	430.990	436.293	435.257
362.570	358.669	355.172	360.192	358.870
77.247	76.095	75.818	76.100	76.387
4.694	4.716	4.685	4.733	4.698
428.809	427.470	431.187	429.134	429.155
30559.229	31389.184	32562.533	29233.153	31503.648
7143.306	7314.122	7402.244	7157.318	7286.558
385.000				
188356.709	186001.182	185705.520	187099.086	186687.801
439.360	435.553	431.073	435.974	435.329
362.284	359.441	354.543	359.884	358.756
77.076	76.112	76.530	76.090	76.573
4.700	4.723	4.633	4.730	4.685
428.707	427.046	430.799	429.152	428.351
28745.203	29591.804	30789.677	27430.808	29708.895
6753.036	6929.092	7015.638	6770.888	6899.255
390.000				
188278.563	185552.203	185206.357	186974.541	186345.605
439.169	434.811	429.888	435.667	434.623
362.107	358.825	353.361	359.588	358.096
77.062	75.986	76.527	76.079	76.525
4.699	4.722	4.617	4.726	4.670
428.715	426.742	430.824	429.169	428.761
26931.912	27794.101	29017.378	25629.964	27914.464
6362.910	6544.031	6628.331	6384.514	6511.757
395.000				
188502.061	185496.555	185167.201	186833.523	186388.604
439.710	434.706	429.762	435.320	434.726
362.610	358.724	353.302	359.253	358.212
77.100	75.982	76.460	76.066	76.514
4.703	4.721	4.621	4.723	4.682
428.696	426.717	430.360	429.187	428.758
25118.363	25997.892	27246.113	23830.677	26120.769
5972.696	6159.165	6241.860	5996.198	6124.573
400.000				
188379.967	186030.227	185692.982	186681.000	186701.057
439.419	435.376	431.145	434.945	435.313
362.345	359.318	354.449	358.892	358.704
77.073	76.058	76.696	76.052	76.509
4.701	4.724	4.621	4.719	4.632
428.703	427.287	430.697	429.206	428.896
23303.967	24199.777	25474.050	22033.168	24325.931
5582.427	5774.529	5655.279	5611.951	5737.412
405.000				
188110.334	185664.869	185404.527	186547.805	186393.262
438.747	434.386	430.398	434.625	434.510
361.715	358.289	353.708	358.595	357.971
77.032	76.097	76.490	76.030	76.539
4.696	4.708	4.627	4.717	4.677
428.744	427.419	430.775	429.216	428.980
21491.564	22404.256	23703.761	20237.330	22533.194
5192.184	5389.211	5468.583	5225.797	5349.993
410.000				
188083.877	185021.607	184635.625	186462.818	185913.703
438.687	434.082	428.366	434.422	433.778
361.656	358.070	351.965	358.410	357.230
77.031	76.011	76.602	76.012	76.548
4.695	4.711	4.595	4.715	4.667
428.743	426.237	430.622	429.221	428.600
19681.695	20610.137	21935.462	18442.698	20742.765
4802.218	5004.152	5079.521	4839.743	4961.964
415.000				
187771.223	185309.430	185084.342	186434.758	186055.154
437.943	434.032	429.399	434.356	433.791
360.984	358.035	353.280	358.355	357.433
76.959	75.997	76.119	76.001	76.358
4.691	4.711	4.641	4.715	4.681
428.757	426.949	431.032	429.221	428.913
17873.490	18816.670	20169.595	16648.668	18953.252
4412.259	4619.359	4692.996	4453.763	4574.868
420.000				
187458.890	185202.703	184952.703	186456.375	185871.432
437.165	434.016	429.151	434.411	433.437
360.188	358.023	352.962	358.416	357.058
76.950	75.993	76.189	75.994	76.379
4.690	4.711	4.633	4.716	4.675
428.826	426.718	430.973	429.217	428.839
16066.524	17023.711	18402.750	14854.600	17164.328
4022.407	4234.658	4308.435	4067.827	4183.500
425.000				
187483.922	185101.361	184876.553	186505.992	185821.344
437.175	432.701	428.375	434.526	432.917
360.195	356.746	352.705	358.528	356.548
76.980	75.955	76.171	75.997	76.359
4.679	4.697	4.630	4.718	4.669
428.853	427.782	431.078	429.218	429.238
14261.753	15233.848	16637.177	13060.077	15377.592
3632.681	3850.281	3924.078	3681.902	3802.347

TABLE AP 1-2 (Sheet 6 of 6)
ENGINE PERFORMANCE PROGRAM (PA49)

430.000				
187408.307	185023.924	184991.344	186566.523	185807.855
437.014	433.769	428.624	434.664	433.136
360.076	357.810	353.407	358.661	357.098
76.939	75.959	75.217	76.003	76.038
4.680	4.711	4.699	4.719	4.696
428.838	426.549	431.594	429.220	428.994
12457.882	13443.493	14871.502	11264.915	13590.959
3242.995	3465.816	3539.675	3295.950	3416.162

435.000				
187472.184	185444.176	185336.707	186627.877	186084.354
437.174	433.809	429.619	434.803	433.534
360.240	357.803	353.945	358.795	357.329
76.933	76.006	75.674	76.008	76.204
4.692	4.708	4.677	4.721	4.689
428.828	427.479	431.398	429.224	429.235
10654.196	11652.856	13104.408	9469.089	11803.820
2853.316	3081.270	3156.430	2909.972	3030.339

440.000				
187581.803	185418.488	185218.307	186641.225	186072.863
437.456	433.990	429.528	434.844	433.658
360.528	358.126	353.639	358.861	357.431
76.928	75.864	75.890	75.983	76.227
4.687	4.721	4.660	4.723	4.689
428.802	427.241	431.213	429.214	429.085
8850.356	9861.949	11339.103	7672.734	10017.136
2463.718	2696.725	2771.665	2524.041	2644.036

445.000				
187862.580	185119.037	184945.852	186638.914	185975.822
438.137	433.986	428.774	434.845	433.632
361.180	358.157	353.135	358.889	357.491
76.957	75.829	75.638	75.956	76.141
4.693	4.723	4.669	4.725	4.695
428.776	426.555	431.337	429.208	428.839
7043.943	8070.009	9573.382	5876.193	8229.112
2074.037	2312.540	2386.687	2139.243	2257.755

450.000				
187958.227	185350.158	185357.434	186674.307	186221.938
438.375	434.648	429.348	434.937	434.174
361.420	358.656	354.304	359.004	358.176
76.955	75.992	75.045	75.933	75.997
4.697	4.720	4.721	4.728	4.712
428.762	426.437	431.718	429.199	428.972
5234.786	6275.701	7803.062	4079.339	6437.850
1684.192	1928.349	2003.028	1752.575	1871.856

455.000				
188496.361	185491.863	185484.139	186838.508	186490.785
439.660	435.381	429.574	435.320	434.872
362.600	359.521	354.675	359.363	358.934
77.054	75.860	74.899	75.957	75.938
4.706	4.739	4.735	4.731	4.727
428.732	426.045	431.786	429.198	428.855
3422.230	4479.113	6030.416	2281.305	4643.920
1294.309	1544.091	1620.668	1366.908	1486.356

458.000				
188545.852	185884.654	185693.461	186958.158	186707.986
439.816	435.444	430.696	435.600	435.319
362.795	359.376	354.696	359.624	358.955
77.021	76.068	76.000	75.976	76.363
4.710	4.724	4.667	4.733	4.701
428.693	426.885	431.148	429.197	428.909
2333.097	3399.554	4965.138	1201.508	3565.930
1060.265	1313.335	1391.577	1135.438	1255.059

458.100				
188537.475	185816.938	185635.137	186962.146	186663.182
439.784	435.424	430.478	435.609	435.229
362.754	359.366	354.573	359.633	358.898
77.029	76.059	75.904	75.976	76.331
4.709	4.725	4.671	4.733	4.702
428.705	426.749	431.231	429.197	428.895
2296.774	3363.576	4929.638	1165.499	3529.996
1052.465	1305.633	1383.891	1127.721	1247.329

458.200				
188548.803	185813.154	185630.242	186966.145	186664.064
439.798	435.384	430.471	435.618	435.218
362.754	359.352	354.578	359.641	358.895
77.044	76.032	75.893	75.977	76.323
4.708	4.726	4.672	4.734	4.702
428.717	426.780	431.225	429.197	428.908
2260.456	3327.597	4894.136	1129.492	3494.063
1044.664	1297.932	1376.206	1120.004	1239.601

458.300				
188558.512	185893.768	185678.336	186970.137	186710.203
439.821	435.397	430.677	435.628	435.298
362.774	359.374	354.628	359.650	358.925
77.047	76.024	76.048	75.977	76.373
4.708	4.727	4.663	4.734	4.700
428.716	426.952	431.132	429.197	428.933
2224.136	3291.617	4858.633	1093.483	3458.129
1036.862	1290.233	1368.505	1112.287	1231.867

458.400				
188575.732	185839.191	185575.145	186974.016	186663.354
439.857	435.995	430.486	435.637	435.446
362.799	359.929	354.339	359.659	359.022
77.057	76.066	76.148	75.978	76.424
4.708	4.732	4.653	4.734	4.698
428.721	426.242	431.083	429.197	428.692
2187.814	3255.608	4823.156	1057.474	3422.193
1029.061	1282.533	1360.794	1104.570	1224.129

458.500				
188586.113	185826.998	185576.756	186977.908	186663.363
439.884	436.073	430.585	435.646	435.514
362.825	359.980	354.417	359.667	359.074
77.053	76.093	76.168	75.979	76.440
4.708	4.731	4.653	4.734	4.697
428.718	426.137	430.988	429.197	428.615
2151.492	3219.567	4787.672	1021.466	3386.244
1021.256	1274.828	1353.082	1096.854	1216.389

458.600				
188563.381	185883.830	185697.453	186981.807	186714.887
439.854	435.440	430.870	435.655	435.388
362.824	359.369	354.792	359.675	358.995
77.030	76.071	76.078	75.979	76.393
4.710	4.724	4.664	4.734	4.699
428.695	426.888	430.983	429.197	428.855
2115.163	3183.559	4752.150	985.453	3350.291
1013.455	1267.125	1345.378	1089.137	1208.653

458.700				
188559.684	185819.295	185670.135	186985.717	186683.035
439.841	435.378	430.661	435.664	435.293
362.808	359.336	354.796	359.684	358.990
77.032	76.041	75.865	75.980	76.313
4.710	4.726	4.677	4.734	4.704
428.700	426.800	431.128	429.197	428.876
2078.838	3147.580	4716.627	949.441	3314.348
1005.657	1259.423	1337.695	1081.420	1200.925

458.800				
188658.703	185809.777	185783.365	186989.635	186750.613
440.000	435.360	430.479	435.673	435.280
362.868	359.324	355.193	359.692	359.128
77.132	76.036	75.286	75.980	76.131
4.705	4.726	4.718	4.734	4.716
428.770	426.795	431.574	429.197	429.046
2042.513	3111.603	4681.066	913.428	3278.394
997.853	1251.723	1330.071	1073.703	1193.216

458.835				
188765.133	178871.035	178745.318	186990.990	182127.160
440.154	434.709	411.706	435.676	428.836
362.905	359.280	339.485	359.695	353.890
77.749	75.428	72.221	75.981	74.966
4.698	4.764	4.701	4.734	4.721
428.861	411.430	434.178	429.197	424.823
2029.797	3099.019	4669.263	900.823	3266.026
995.119	1249.069	1327.532	1071.002	1190.573

AP 2

ABBREVIATIONS

TABLE AP 2-1 (Sheet 1 of 2)
ABBREVIATIONS

ITEM	TERM	ITEM	TERM
ac	Alternating current	F	Fahrenheit, thrust
Act	Actuator	FCI	Flight Critical Items
APS	Auxiliary Propulsion System	Flt	Flight
ASI	Augmented Spark Igniter	ft	Feet
attch	Attach	FM	Frequency modulation
Aux	Auxiliary	FTC	Florida Test Center
Btu	British thermal unit	Fwd	Forward
Bgr	Bridge gain ratio	GG	Gas generator
Cfm	Cubic feet per minute	GH2	Gaseous hydrogen
Contr	Control	GIS	Ground Instrumentation System
cps	Cycles per second	GN2	Gaseous nitrogen
db	Decibel	gpm	Gallons per minute
dc	Direct current	GSE	Ground support equipment
DDAS	Digital Data Acquisition System	He	Helium
deg	Degree	Hg	Mercury
DER	Digital Events Recorder	H_2O	Water
Disch	Discharge	hr	Hour
DNA	Data not available	hp	Horsepower
D/O	Dropout	Hyd	Hydraulic
DPF	Differential Pressure Feedback	Hz	Hertz
EBW	Exploding bridgewire	in.	Inch
ECC	Engine Cutoff Command	IP&CL	Instrumentation Program and Component List
ECO	Engine Cutoff	I_{sp}	Specific Impulse
EDS	Emergency Detection System	IU	Instrument Unit
E/I	External/Internal	K	Kilo = 1,000 or 10^3
EMI	Electromagnetic Interference	Kc	Kilocycle
EMR	Engine Mixture Ratio	KSC	Kennedy Space Center
ESC	Engine Start Command	lbf	Pounds force
		lbm	Pounds mass

TABLE AP 2-1 (Sheet 2 of 2)
ABBREVIATIONS

ITEM	TERM
LH2	Liquid Hydrogen
Loc	Location
LOX	Liquid oxygen
M&A	Manufacturing and Assembly
ms	Millisecond
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
N/A	Not applicable
NPSH	Net positive suction head
PCM	Pulse code modulation
PDT	Pacific Daylight Time
pf	Picofarad
Posit	Position
pps	Pulses per second
Press	Pressure
psi	Pounds per square inch
psia	Pounds per square inch, absolute
psid	Pounds per square inch, differential
psig	Pounds per square inch, gauge
PST	Pacific Standard Time
Pt	Point
P/U	Pickup
PU	Propellant Utilization
Pwr	Power
R	Rankine
RACS	Remote Analog Checkout System
RAD	Radial
Refl	Reflected
Reg	Regulator
RF	Radio Frequency
RMR	Reference Mixture Ratio
RPM	Revolutions per minute
RSS	Root sum square
SAI	Special Attention Items
SCC	Standard cubic centimeter
SCI	Standard cubic inch
scim	Standard cubic inch per minute
scfm	Standard cubic foot per minute
sec	Second
sps	Samples per second
STC	Sacramento Test Center
sw	Switch
Syst	System
T_0	Simulated liftoff
TAN	Tangential
Temp	Temperature
T/M	Telemetry
TP&E	Test Planning and Evaluation
Vac	Volts alternating current (100 vac)
V	Volts
VCL	Vertical Checkout Laboratory
vdc	Volts direct current
Vib	Vibration
vswr	Voltage standing wave ratio
$\dot{W}_T$	Total flowrate

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